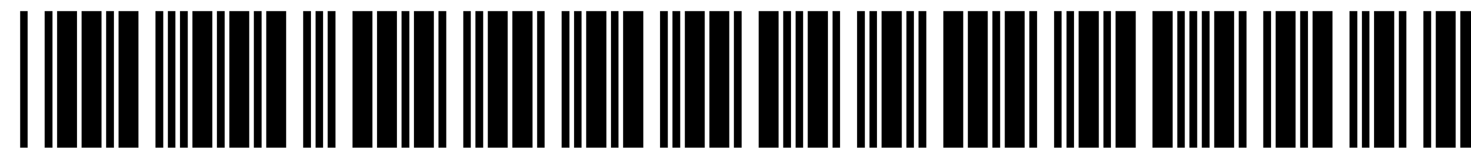

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Kohno

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(45) **Date of Patent: Feb. 15, 2022**

(54) **METHOD OF CONTROLLING TRANSMISSION ELECTRON MICROSCOPE AND TRANSMISSION ELECTRON MICROSCOPE**

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(72) Inventor: **Yuji Kohno**, Tokyo (JP)

(73) Assignee: **JEOL Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 54 days.

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H01J 37/141 (2006.01)
H01J 37/26 (2006.01)
H01J 37/295 (2006.01)

(52) **U.S. Cl.**
CPC ***H01J 37/268*** (2013.01); ***H01J 37/141*** (2013.01); ***H01J 37/295*** (2013.01); *H01J 2237/04922* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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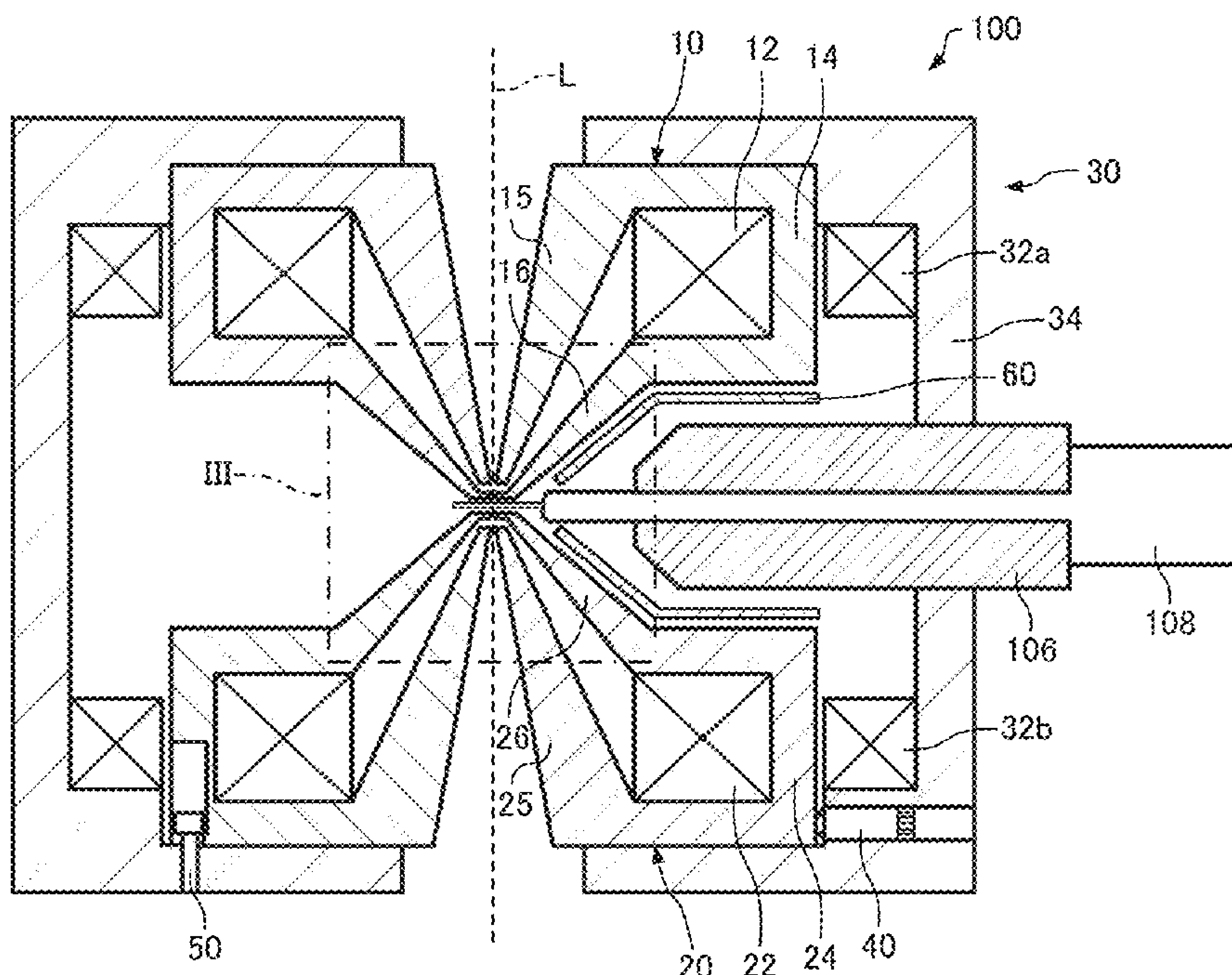
(74) *Attorney, Agent, or Firm* — The Webb Law Firm

(57) **ABSTRACT**

A method of controlling a transmission electron microscope includes: causing a first magnetic field lens to generate a first magnetic field and causing a second magnetic field lens to generate a second magnetic field; causing the magnetic field applying unit to generate a magnetic field of a direction along an optical axis on a specimen mounting surface; and changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of an objective lens due to the magnetic field generated by the magnetic field applying unit.

7 Claims, 15 Drawing Sheets



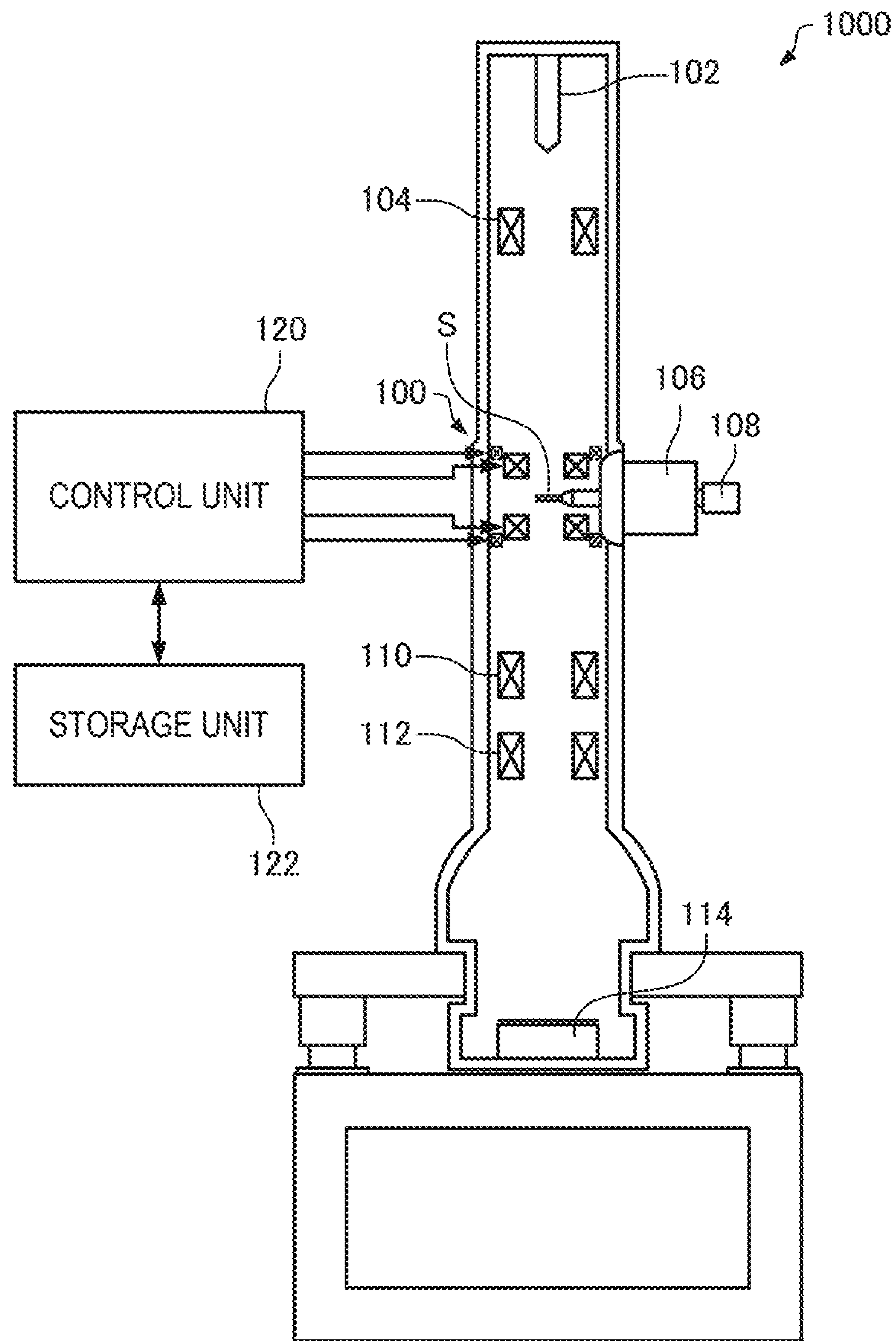


FIG. 1

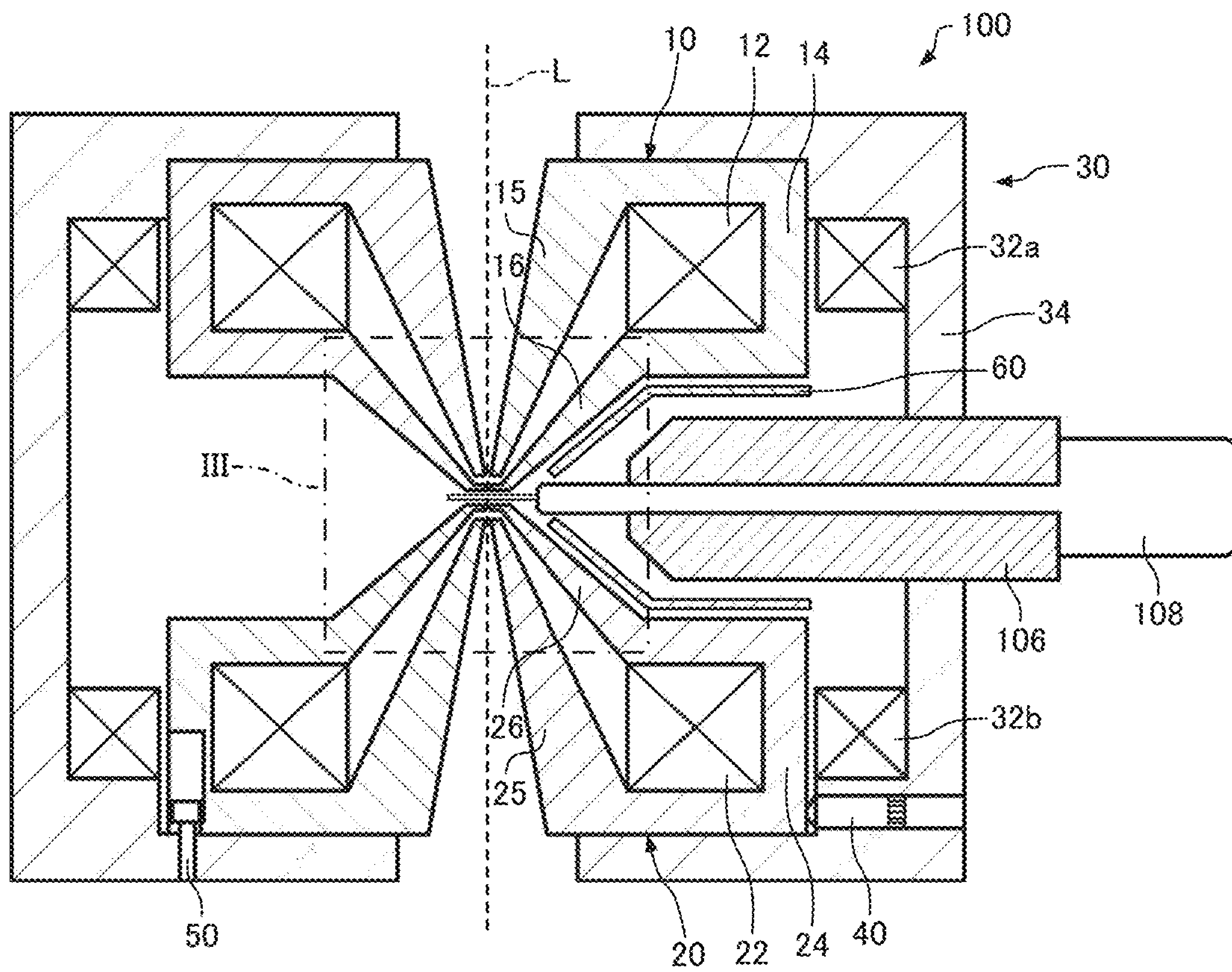


FIG. 2

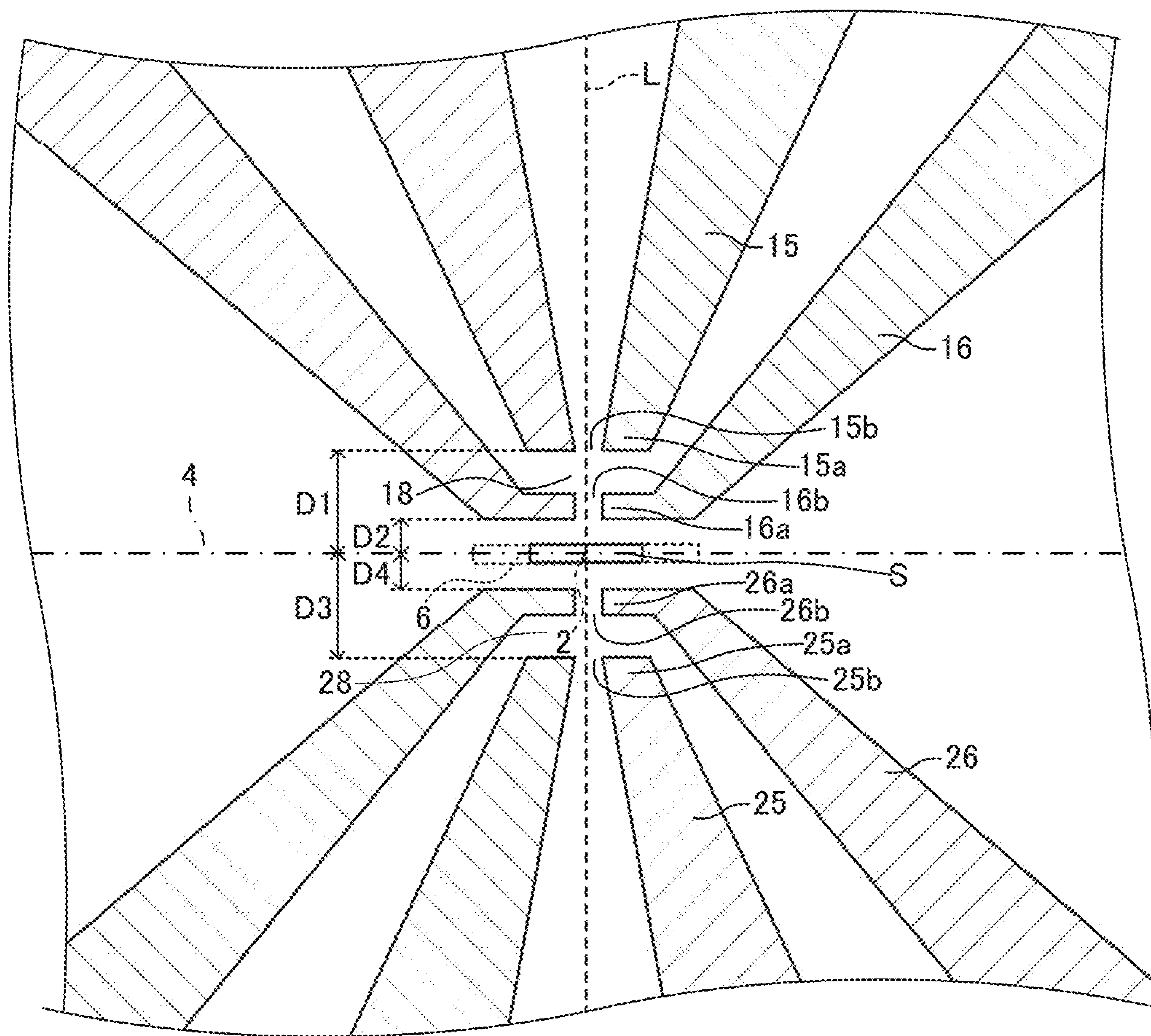


FIG. 3

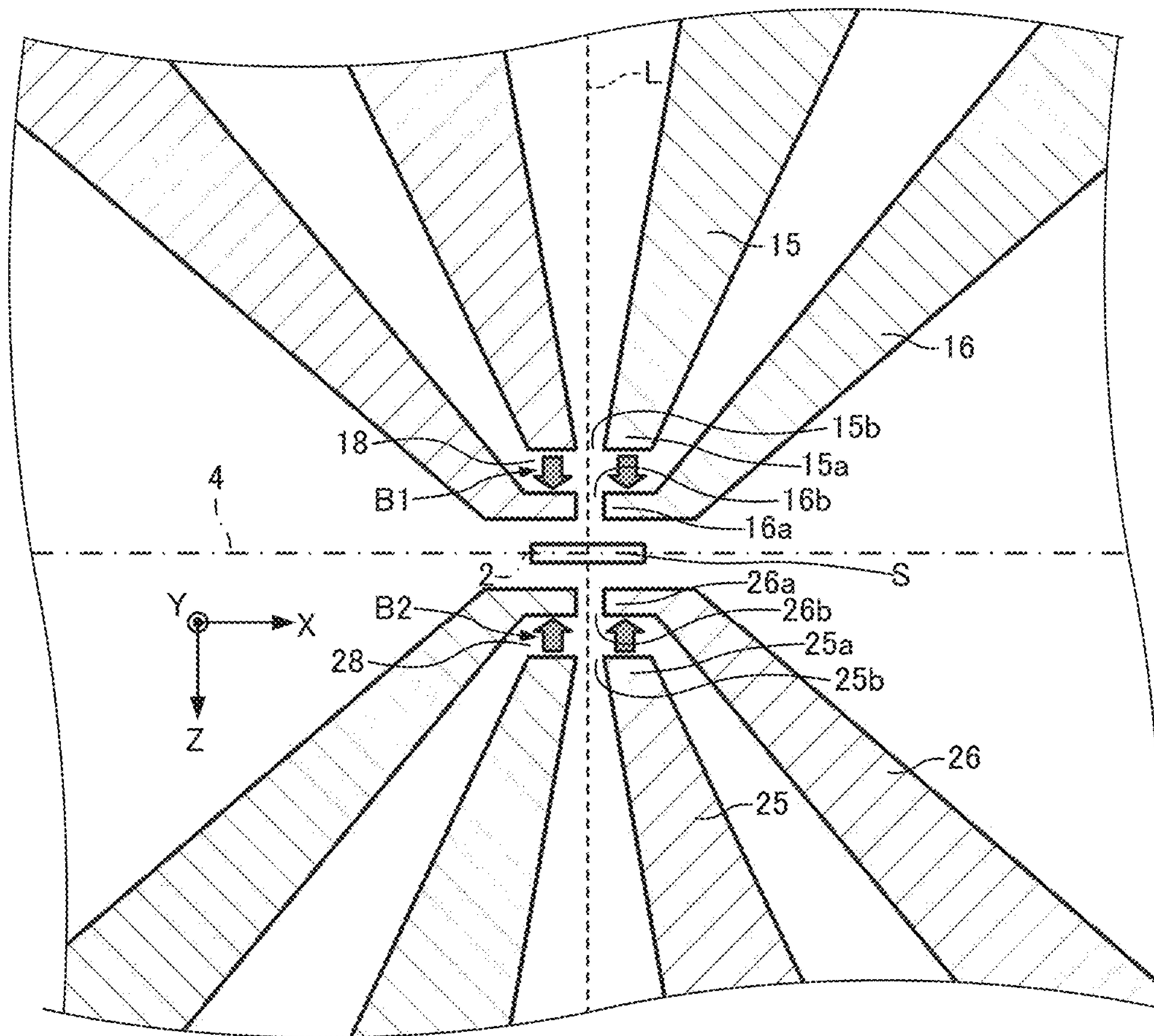


FIG. 4

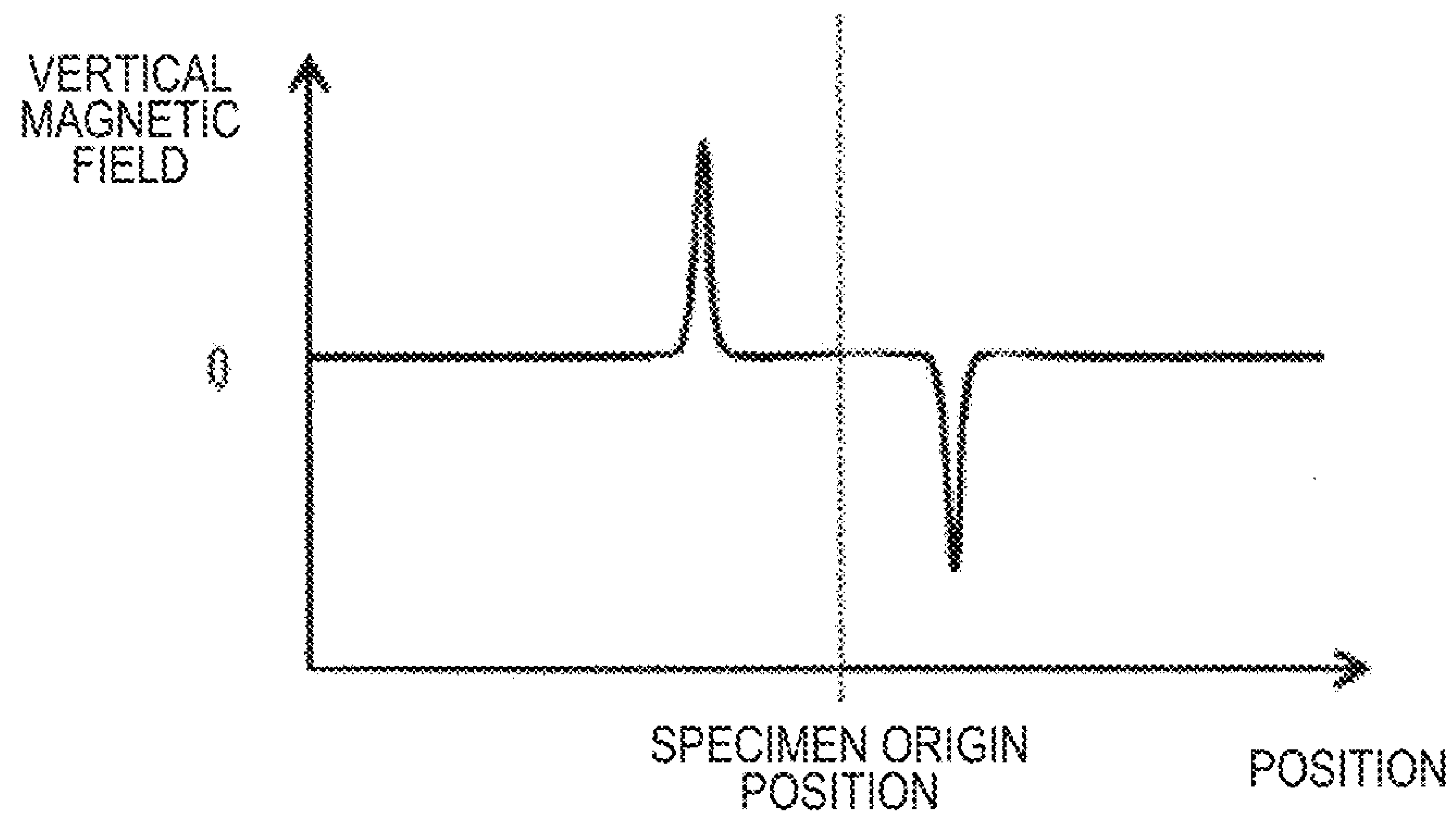


FIG. 5

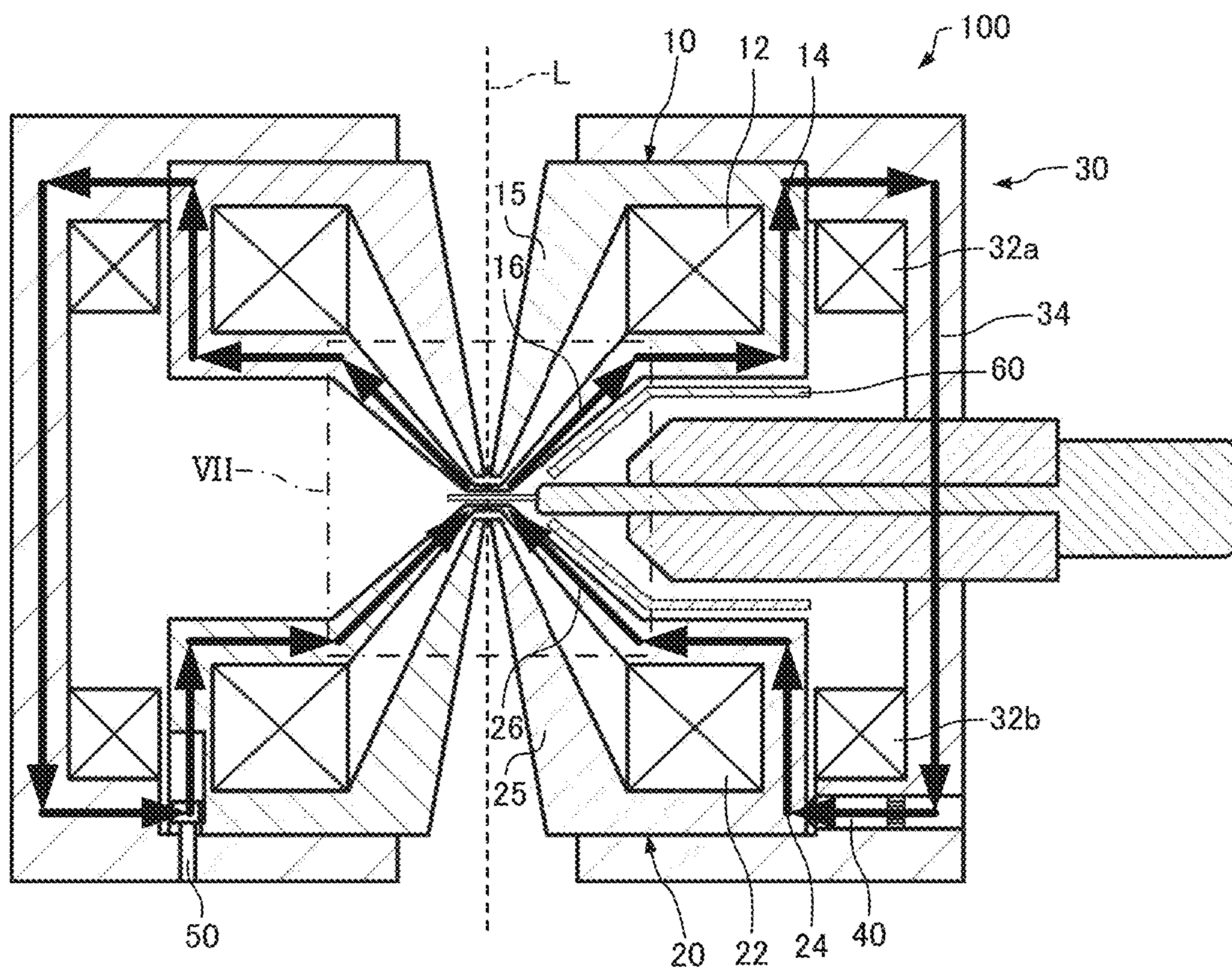


FIG. 6

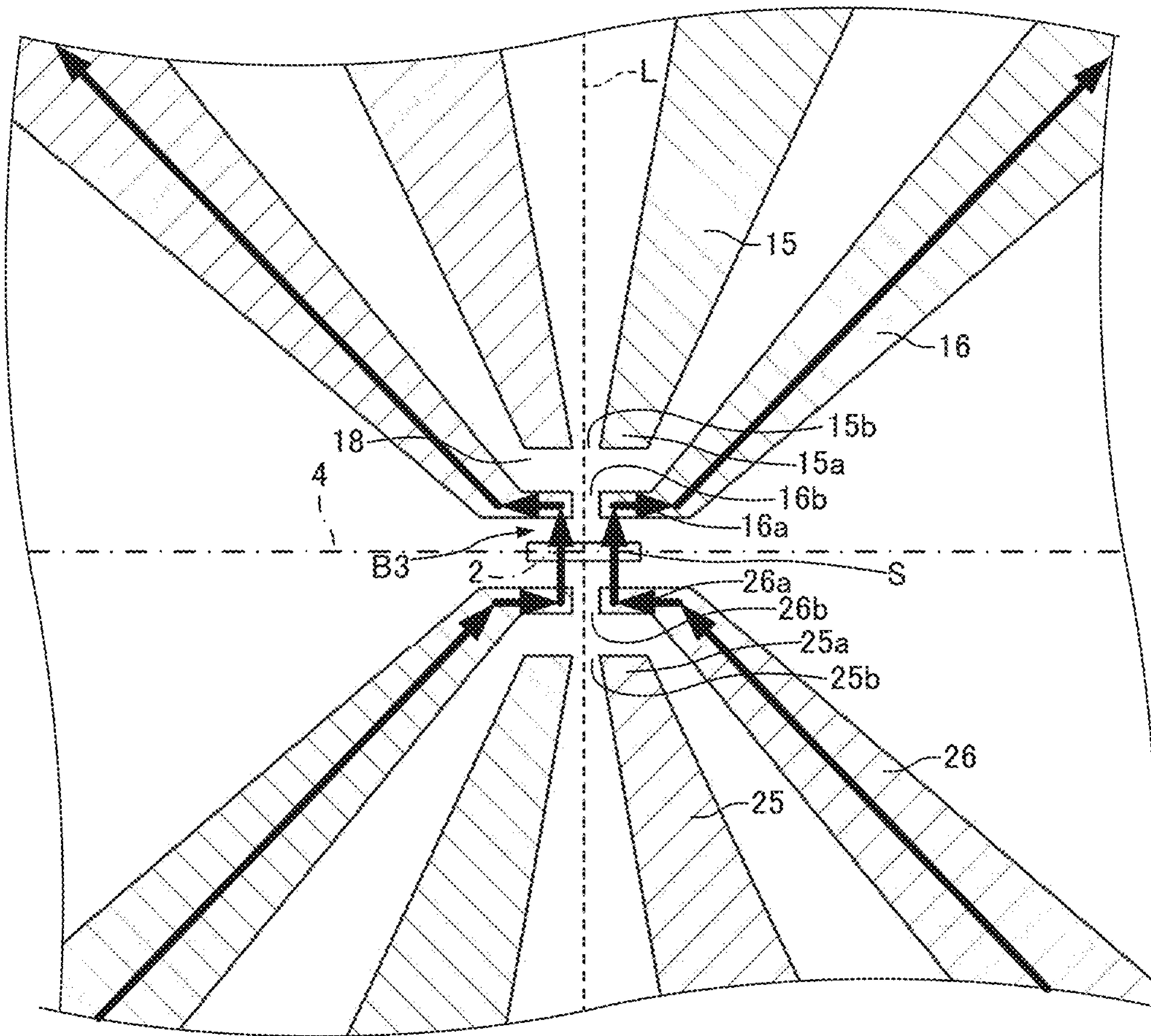


FIG. 7

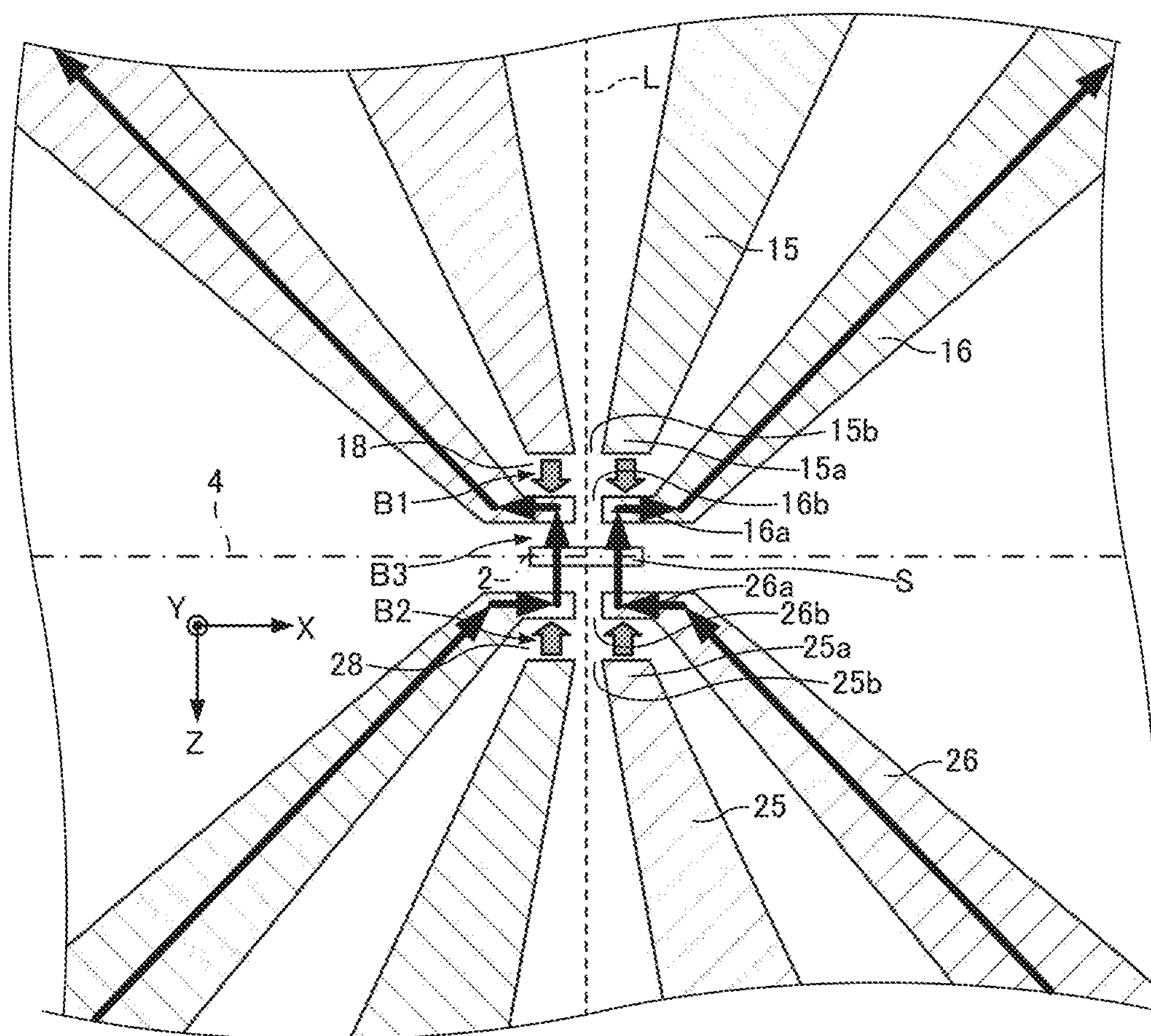


FIG. 8

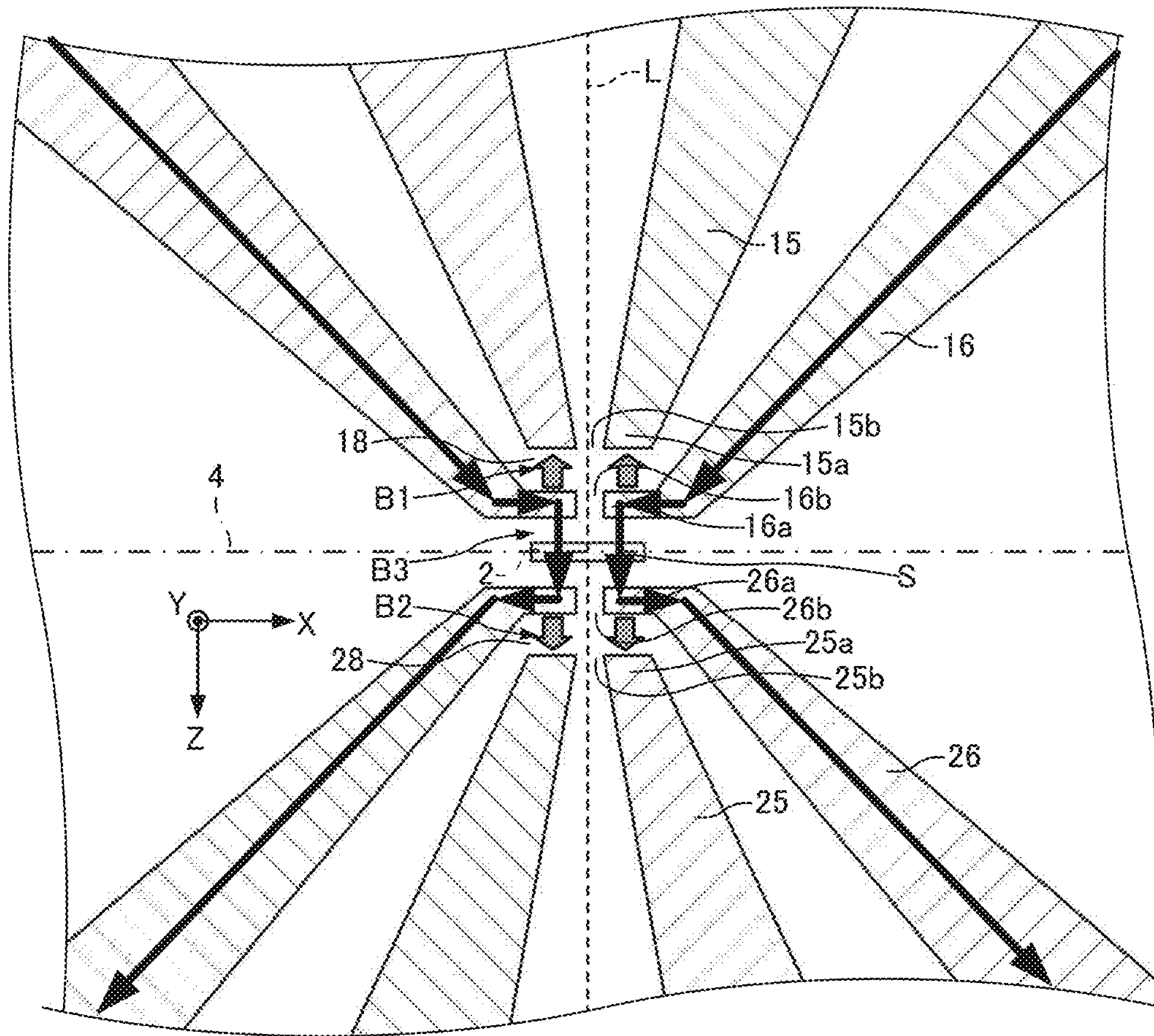


FIG. 9

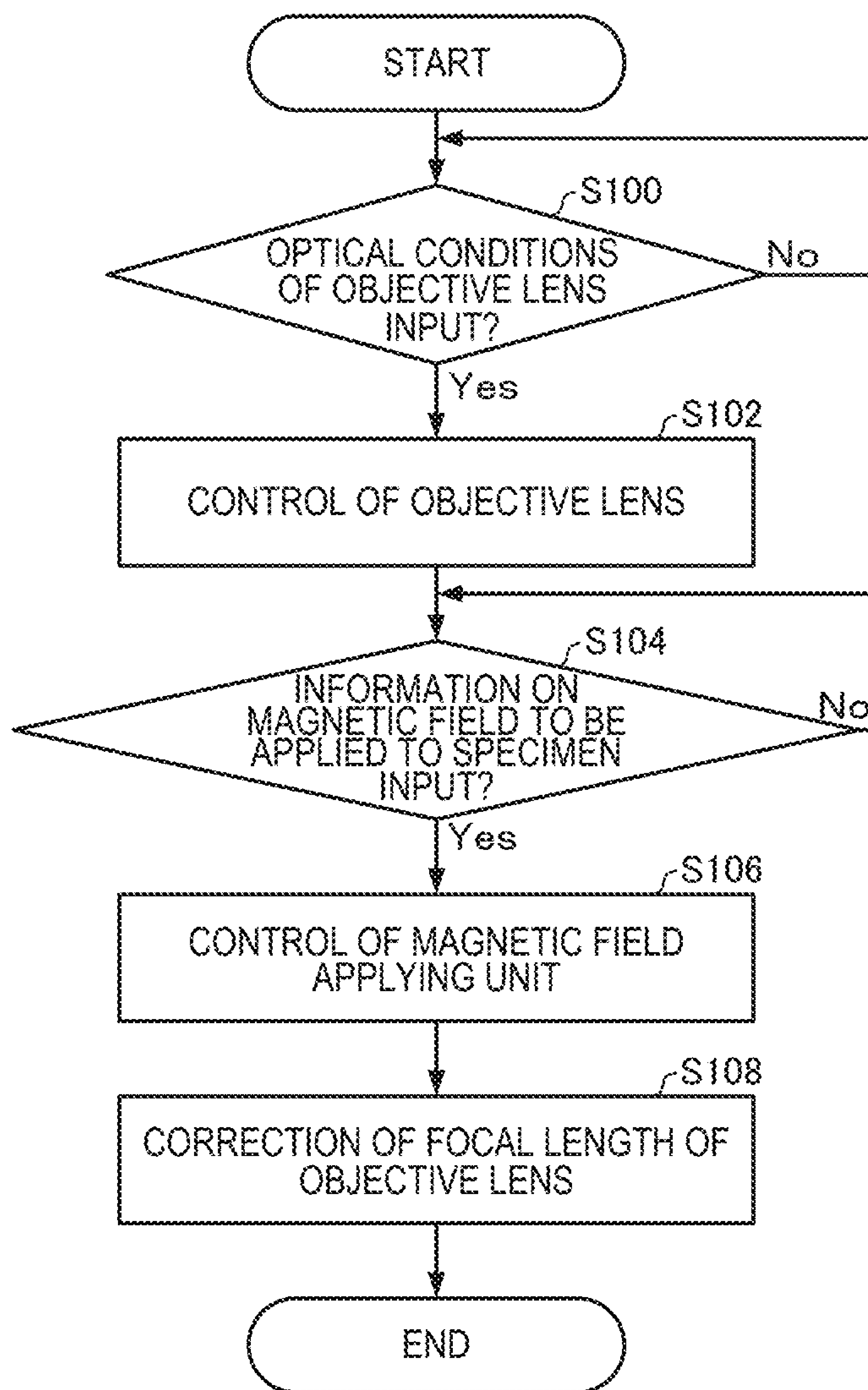


FIG. 10

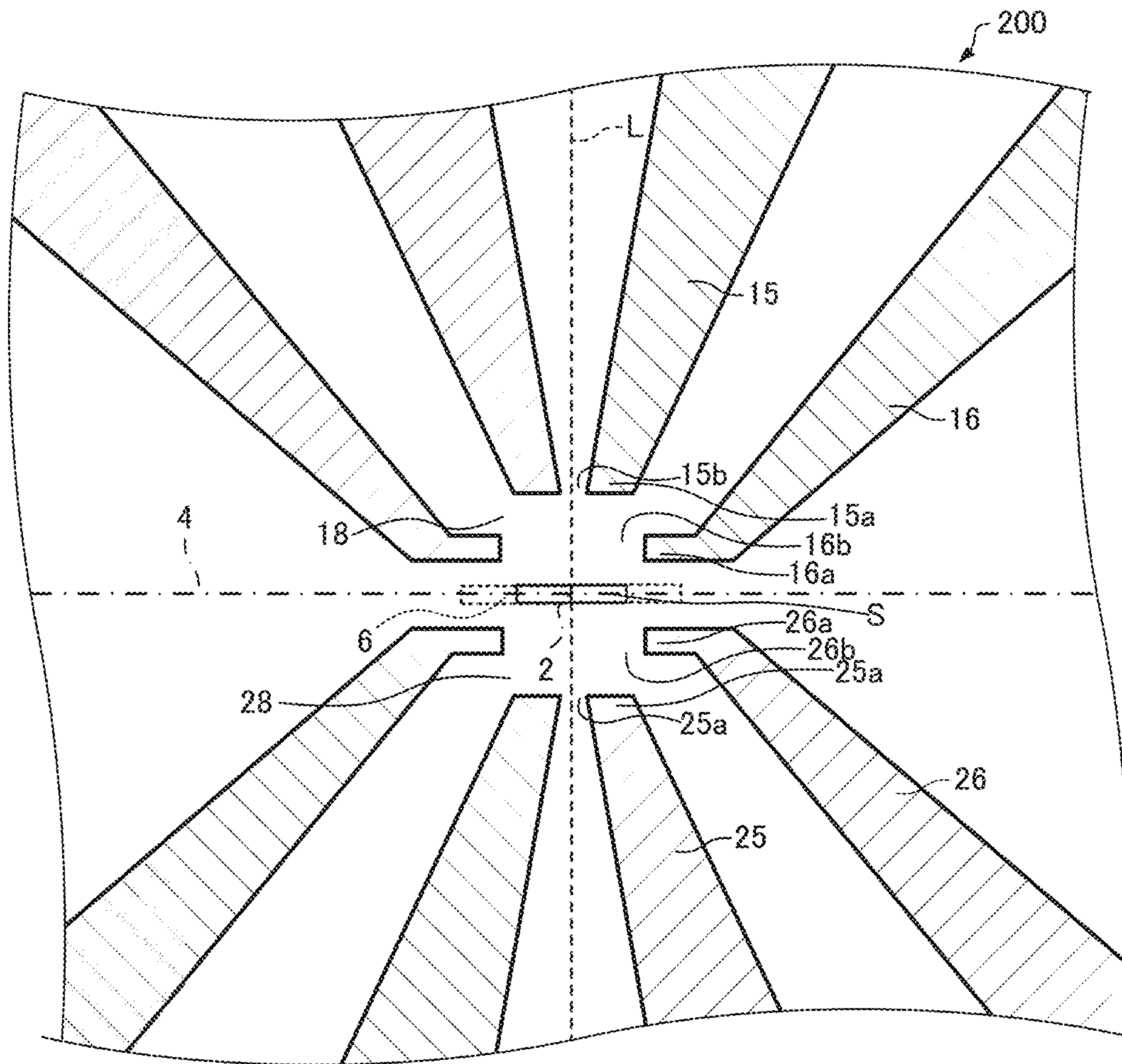


FIG. 11

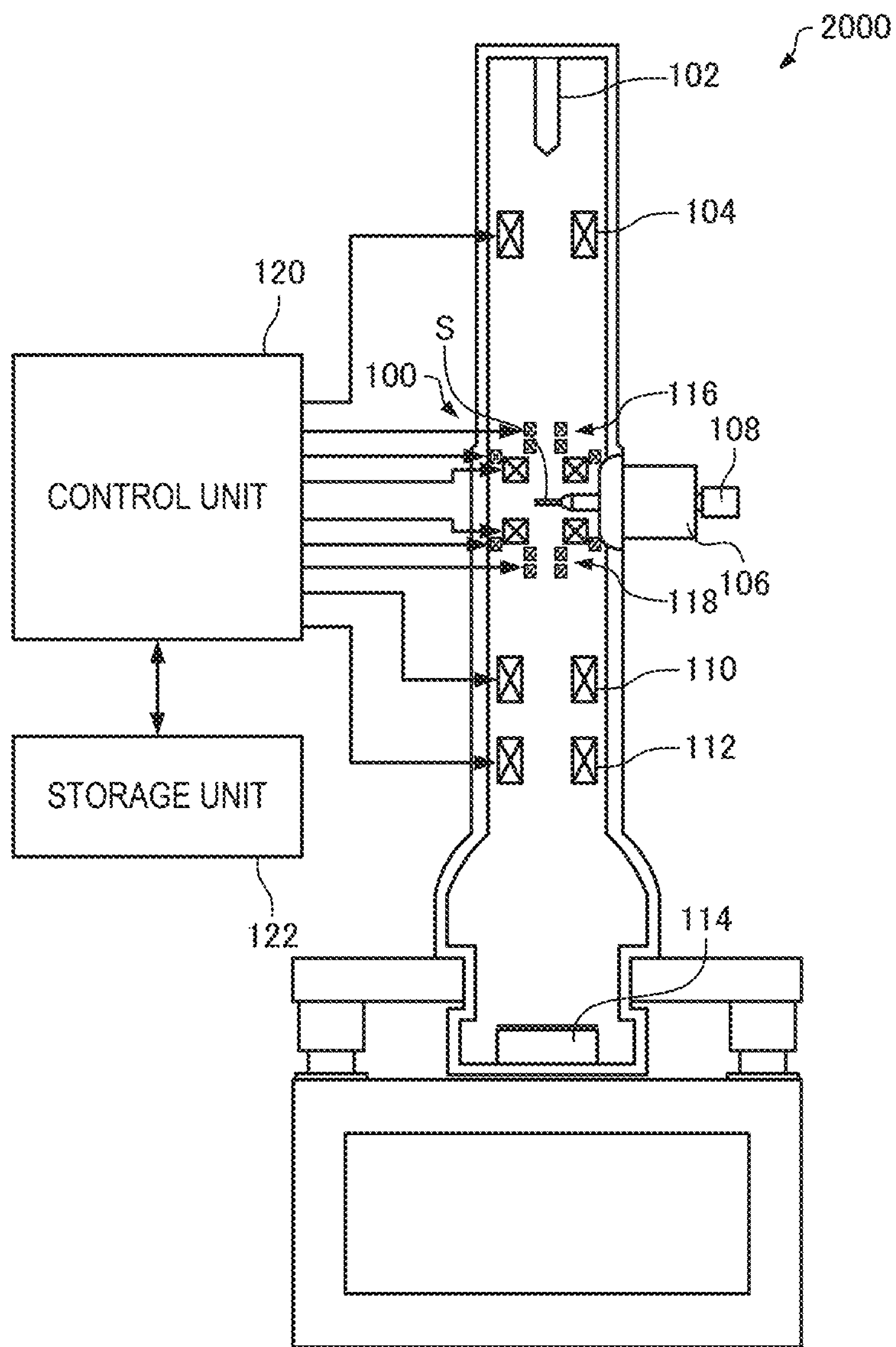


FIG. 12

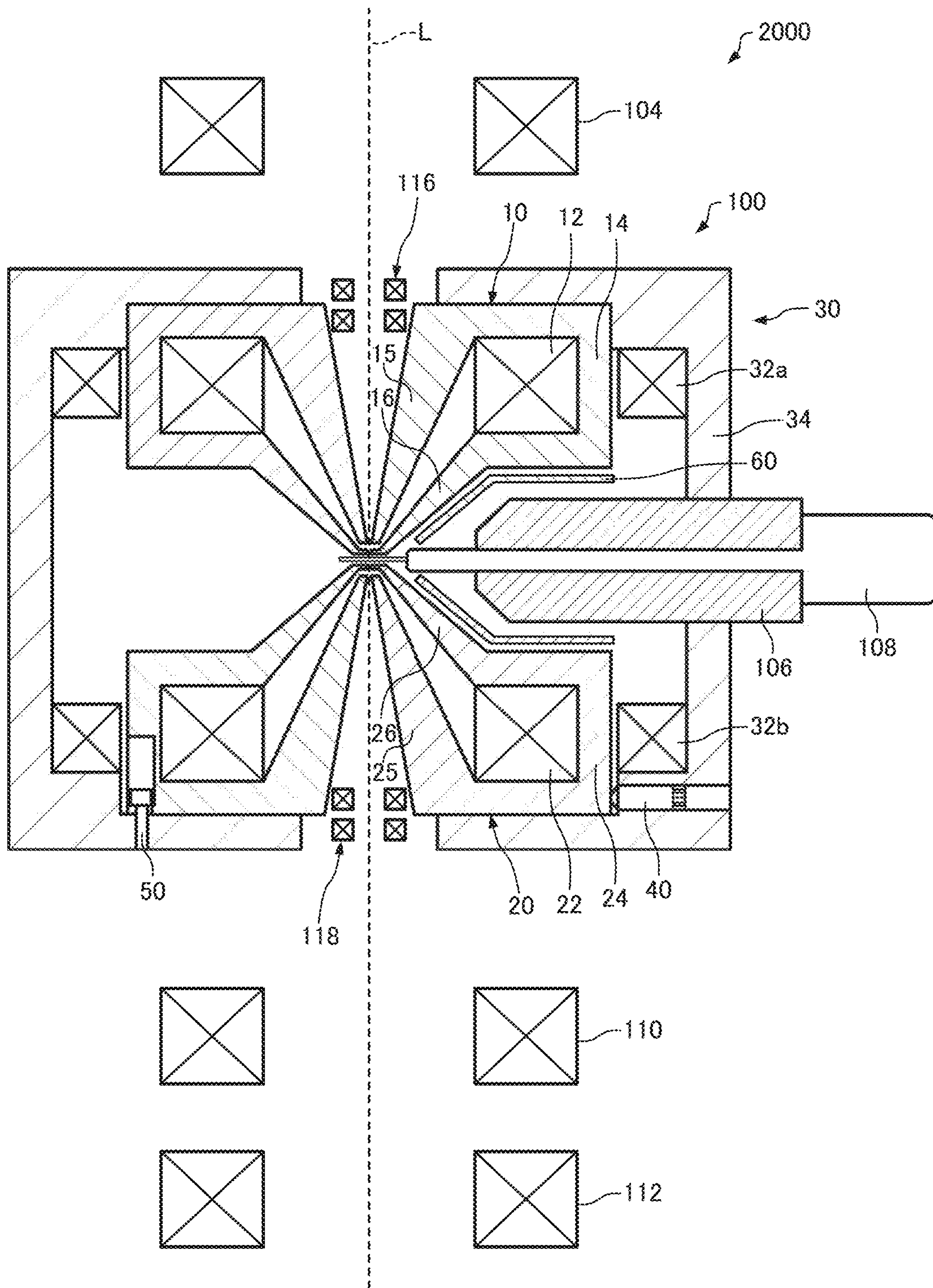


FIG. 13

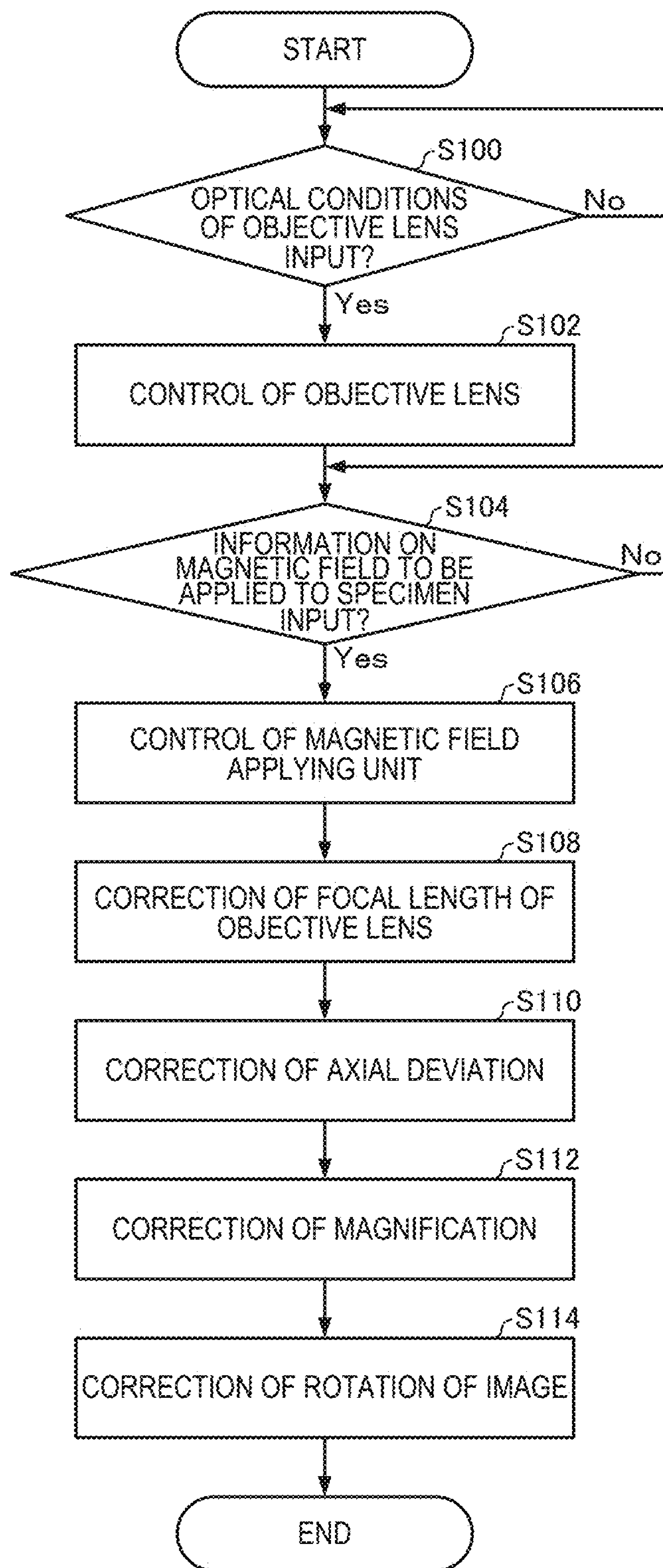


FIG. 14

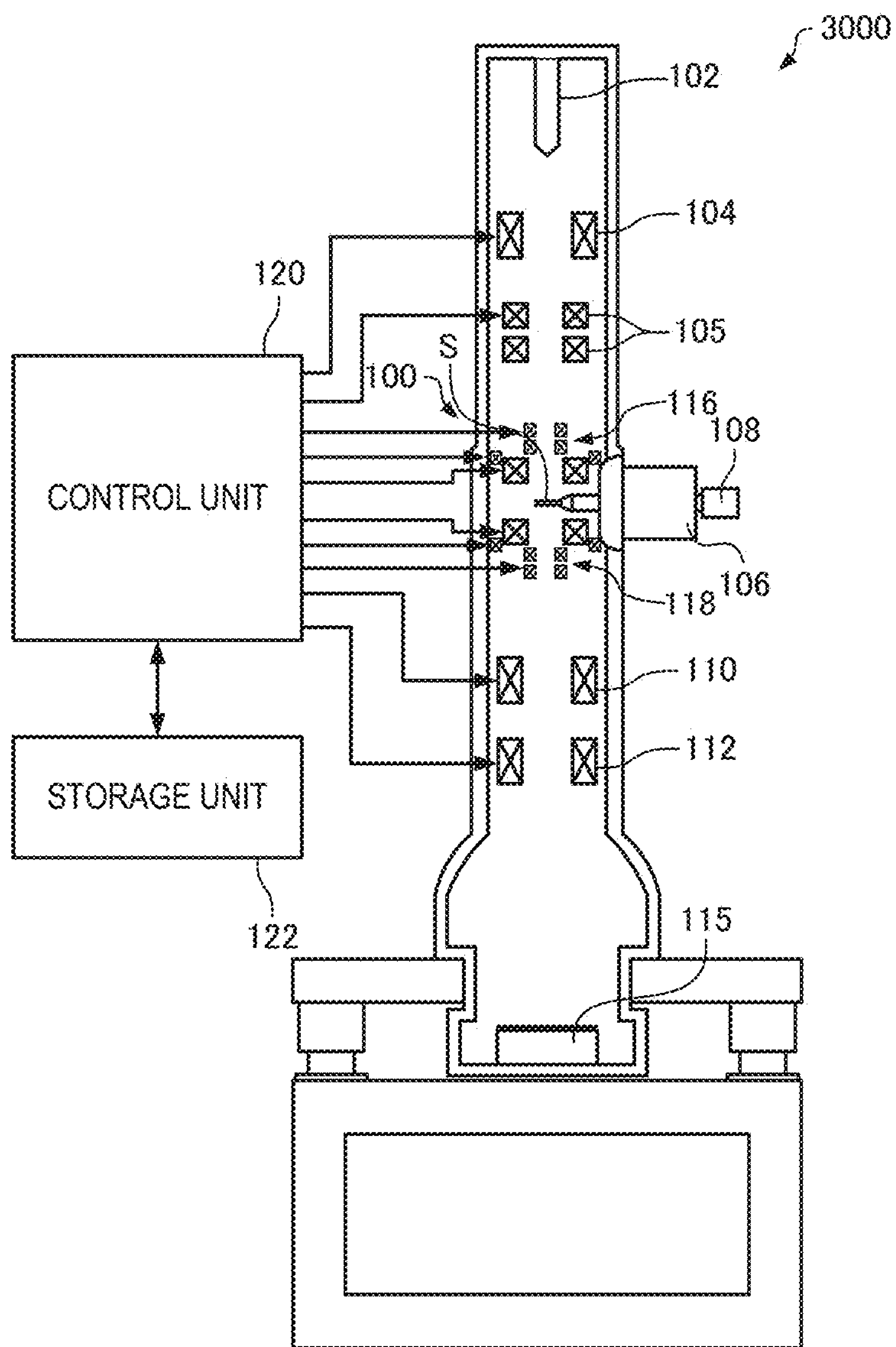


FIG. 15

METHOD OF CONTROLLING TRANSMISSION ELECTRON MICROSCOPE AND TRANSMISSION ELECTRON MICROSCOPE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to Japanese Patent Application No. 2019-063461, filed Mar. 28, 2019, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a method of controlling a transmission electron microscope and to a transmission electron microscope.

Description of Related Art

Magnetic field objective lenses are known as objective lenses of transmission electron microscopes. Improvements have been made to magnetic field objective lenses so that a focal length of the lenses is reduced by generating a ferromagnetic field on a specimen or in a vicinity of the specimen.

However, when observing a specimen that is sensitive to a magnetic field such as a magnetic specimen with a transmission electron microscope, there is a problem that a magnetic field generated by an objective lens causes a magnetic property of the specimen to change. When the magnetic field of the objective lens is provided at a position that is separated from the specimen in order to prevent the specimen from being affected by the magnetic field, a focal length of the objective lens increases and causes a resolution of the electron microscope to decline. Therefore, it is difficult to appropriately observe a magnetic specimen at a high resolution using a magnetic field objective lens.

In consideration of such problems, JP-A-2018-49728 discloses an objective lens that includes a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface, the first magnetic field lens and the second magnetic field lens being provided so that a component along the optical axis of a magnetic field generated by the first magnetic field lens and a component along the optical axis of a magnetic field generated by the second magnetic field lens cancel each other out on the specimen mounting surface.

The objective lens disclosed in JP-A-2018-49728 includes a magnetic field applying unit for applying an arbitrary magnetic field to a specimen. Accordingly, for example, when the specimen is a magnetic material, a process by which a magnetic property is changed by a magnetic field and the like can be observed.

However, with the objective lens disclosed in JP-A-2018-49728, there are cases where a focal length of the objective lens changes due to leakage of the magnetic field generated by the magnetic field applying unit into the objective lens.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a method of controlling a transmission electron microscope that includes an objective lens,

the objective lens including:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field applying unit which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole, and

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other, and

the method of controlling a transmission electron microscope including:

causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

causing the magnetic field applying unit to generate a magnetic field of a direction along the optical axis on the specimen mounting surface; and

changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field applying unit.

According to a second aspect of the invention, there is provided a transmission electron microscope including:

an objective lens; and

a control unit that controls the objective lens,

the objective lens including:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field applying unit which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole, and

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other, and

the control unit performing:

processing of causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

processing of causing the magnetic field applying unit to generate a magnetic field of a direction along the optical axis on the specimen mounting surface; and

processing of changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field applying unit.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a configuration of a transmission electron microscope according to a first embodiment.

FIG. **2** is a sectional view schematically illustrating an objective lens.

FIG. **3** is a sectional view schematically illustrating the objective lens.

FIG. **4** is a diagram for illustrating magnetic fields generated by a first magnetic field lens and a second magnetic field lens.

FIG. **5** is a diagram illustrating a distribution of vertical magnetic fields that are generated by the first magnetic field lens and the second magnetic field lens.

FIG. **6** is a diagram for illustrating operations of a magnetic field applying unit.

FIG. **7** is a diagram for illustrating operations of the magnetic field applying unit.

FIG. **8** is a diagram schematically illustrating how a magnetic field is applied to a specimen.

FIG. **9** is a diagram schematically illustrating how a magnetic field is applied to the specimen.

FIG. **10** is a flow chart illustrating an example of processing by a control unit of the transmission electron microscope according to the first embodiment.

FIG. **11** is a sectional view schematically illustrating an objective lens according to a modification.

FIG. **12** is a diagram schematically illustrating a transmission electron microscope according to a second embodiment.

FIG. **13** is a diagram schematically illustrating substantial parts of the transmission electron microscope according to the second embodiment.

FIG. **14** is a flow chart illustrating an example of processing by a control unit of the transmission electron microscope according to the second embodiment.

FIG. **15** is a diagram illustrating a configuration of a transmission electron microscope according to a third embodiment.

DESCRIPTION OF THE INVENTION

(1) According to an embodiment of the invention, there is provided a method of controlling a transmission electron microscope including an objective lens,

the objective lens including:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field applying unit which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole,

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other, and

the method of controlling a transmission electron microscope including:

causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

causing the magnetic field applying unit to generate a magnetic field of a direction along the optical axis on the specimen mounting surface; and

changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field applying unit.

With the method of controlling a transmission electron microscope described above, a deviation of the focal length of the objective lens caused by the magnetic field generated by the magnetic field applying unit can be corrected. Therefore, a good transmission electron microscope image can be obtained in a state where an arbitrary magnetic field is applied to the specimen.

(2) According to an embodiment of the invention, there is provided a transmission electron microscope including:

an objective lens; and

a control unit that controls the objective lens,

the objective lens including:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich

a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field applying unit which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole,

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other, and

the control unit performing:

processing of causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

processing of causing the magnetic field applying unit to generate a magnetic field of a direction along the optical axis on the specimen mounting surface; and

processing of changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field applying unit.

With the transmission electron microscope described above, a deviation of the focal length of the objective lens caused by the magnetic field generated by the magnetic field applying unit can be corrected. Therefore, a good transmission electron microscope image can be obtained in a state where an arbitrary magnetic field is applied to the specimen.

Embodiments of the invention are described in detail below with reference to the drawings. Note that the following embodiments do not unduly limit the scope of the invention as stated in the claims. In addition, all of the elements described below are not necessarily essential requirements of the invention.

1. First Embodiment

1.1 Configuration of Transmission Electron Microscope

First, a configuration of a transmission electron microscope according to a first embodiment will be described with reference to the drawings. FIG. **1** is a diagram illustrating a configuration of a transmission electron microscope **1000** according to the first embodiment.

The transmission electron microscope **1000** includes an objective lens **100**. It should be noted that FIG. **1** illustrates the objective lens **100** and a specimen stage **106** in a simplified manner for the sake of brevity.

As illustrated in FIG. **1**, the transmission electron microscope **1000** includes an electron source **102**, an illumination lens **104**, the objective lens **100**, the specimen stage **106**, a specimen holder **108**, an intermediate lens **110**, a projector lens **112**, an imaging device **114**, a control unit **120**, and a storage unit **122**.

The electron source **102** generates electrons. The electron source **102** is, for example, an electron gun which accelerates electrons emitted from a cathode by an anode and which emits an electron beam.

The illumination lens **104** causes the electron beam discharged from the electron source **102** to converge and illuminates a specimen S with the converged electron beam. Although not illustrated, the illumination lens **104** may be constituted by a plurality of electron lenses.

The specimen stage **106** holds the specimen S. In the illustrated example, the specimen stage **106** holds the specimen S via the specimen holder **108**. The specimen S can be positioned using the specimen stage **106**. For example, the specimen stage **106** is a goniometer stage that is capable of tilting the specimen S.

The objective lens **100** is a first-stage lens for forming a transmission electron microscope image with an electron beam transmitted through the specimen S. Details of the objective lens **100** will be described in "1.2. Configuration of Objective Lens" provided later.

The intermediate lens **110** and the projector lens **112** enlarge the image formed by the objective lens **100** and produce an image on the imaging device **114**. The objective lens **100**, the intermediate lens **110**, and the projector lens **112** constitute an imaging system of the transmission electron microscope **1000**.

The imaging device **114** photographs a transmission electron microscope image formed by the imaging system. For example, the imaging device **114** is a digital camera such as a charge coupled device (CCD) camera or a complementary metal-oxide-semiconductor (CMOS) camera.

The control unit **120** controls the objective lens **100**. A method of controlling the objective lens **100** will be described later. Functions of the control unit **120** can be realized by having various processors (a central processing unit (CPU) and the like) execute programs. It should be noted that at least a part of the functions of the control unit **120** may be realized by a dedicated circuit such as an ASIC (a gate array or the like).

The storage unit **122** stores programs and data which cause or allow the control unit **120** to perform various types of calculation processing and control processing. In addition, the storage unit **122** is also used as a work area of the control unit **120**. The storage unit **122** can be realized by, for example, a random access memory (RAM), a read only memory (ROM), and a hard disk.

1.2. Configuration of Objective Lens

Next, a configuration of the objective lens **100** will be described with reference to the drawings. FIG. **2** is a sectional view schematically illustrating the objective lens **100**. It should be noted that FIG. **2** illustrates a state where the specimen holder **108** is inserted into the specimen stage **106**. FIG. **3** is a sectional view which schematically illustrates the objective lens **100** and which is an enlarged view of a region III in FIG. **2**.

As illustrated in FIG. **2**, the objective lens **100** includes a first magnetic field lens **10**, a second magnetic field lens **20**, a magnetic field applying unit **30**, a position adjusting unit **40**, a fixing unit **50**, and an anti-magnetic tube **60**. It should

be noted that FIG. **3** only illustrates the first magnetic field lens **10** and the second magnetic field lens **20** for the sake of brevity.

The first magnetic field lens **10** and the second magnetic field lens **20** are arranged along an optical axis L of the objective lens **100**. The first magnetic field lens **10** is positioned above (on a side of the illumination lens **104** of) a specimen mounting surface **2**, and the second magnetic field lens **20** is positioned below (on a side of the intermediate lens **110** of) the specimen mounting surface **2**. The first magnetic field lens **10** and the second magnetic field lens **20** are arranged so as to sandwich the specimen mounting surface **2**.

In the objective lens **100**, the specimen S is arranged on the specimen mounting surface **2** between the first magnetic field lens **10** and the second magnetic field lens **20**. The specimen mounting surface **2** is a surface perpendicular to the optical axis L. The specimen mounting surface **2** is a surface on which the specimen S is arranged in the objective lens **100**. For example, the specimen mounting surface **2** is a surface which is centered on a specimen origin position (in other words, a position where the optical axis L and the specimen mounting surface **2** intersect) and which has a sufficient size to arrange the specimen S. The specimen stage **106** is a specimen stage that adopts a side entry system to which the specimen holder **108** is inserted from a direction (a horizontal direction) that is perpendicular to the optical axis L with respect to the first magnetic field lens **10** and the second magnetic field lens **20**.

The first magnetic field lens **10** and the second magnetic field lens **20** are provided so that a component in a direction (a vertical direction) along the optical axis L of the magnetic field generated by the first magnetic field lens **10** and a component in the direction along the optical axis L of the magnetic field generated by the second magnetic field lens **20** cancel each other out on the specimen mounting surface **2**.

The first magnetic field lens **10** has a first excitation coil **12** and a first yoke **14**. The first excitation coil **12** is connected to a power supply (not illustrated). The first yoke **14** is provided so as to surround the first excitation coil **12**. The first yoke **14** has an inner magnetic pole **15** (an example of the first inner magnetic pole) and an outer magnetic pole **16** (an example of the first outer magnetic pole).

The inner magnetic pole **15** and the outer magnetic pole **16** have a ring shape. The inner magnetic pole **15** is arranged on a side of the optical axis L, and the outer magnetic pole **16** is arranged on an outer side of the inner magnetic pole **15**. The outer magnetic pole **16** is arranged on an outer side of the inner magnetic pole **15**. The inner magnetic pole **15** extends toward the specimen mounting surface **2** from a portion that surrounds the first excitation coil **12**. In a similar manner, the outer magnetic pole **16** extends toward the specimen mounting surface **2** from a portion that surrounds the first excitation coil **12**.

A distance D2 between a tip section **16***a* of the outer magnetic pole **16** and the specimen mounting surface **2** is shorter than a distance D1 between a tip section **15***a* of the inner magnetic pole **15** and the specimen mounting surface **2**. In other words, in the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** is positioned between the tip section **15***a* of the inner magnetic pole **15** and the specimen mounting surface **2**.

The tip section **16***a* of the outer magnetic pole **16** cantilevers toward the optical axis L. In other words, the tip section **16***a* of the outer magnetic pole **16** is positioned on a side of the optical axis L as compared to other portions of the outer magnetic pole **16**.

When viewed from the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** overlaps with a specimen movable region **6**. In addition, when viewed from the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** overlaps with the tip section **15***a* of the inner magnetic pole **15**. A distance between the tip section **15***a* of the inner magnetic pole **15** and the optical axis L is equal to a distance between the tip section **16***a* of the outer magnetic pole **16** and the optical axis L.

In this case, the specimen movable region **6** refers to a region where the specimen S supported by the specimen holder **108** is movable by an action of the specimen stage **106**. For example, when a diameter of the specimen S is 3 mm, the specimen stage **106** is capable of moving the specimen S by around ±1.2 mm centered on the specimen origin position within a virtual plane **4** that includes the specimen mounting surface **2**. In this case, a width of the specimen movable region **6** is ±2.7 mm centered on the specimen origin position.

A center of an opening **15***b* that is defined by the tip section **15***a* of the inner magnetic pole **15** is positioned above the optical axis L. In a similar manner, a center of an opening **16***b* that is defined by the tip section **16***a* of the outer magnetic pole **16** is positioned above the optical axis L. A shape of the opening **15***b* of the inner magnetic pole **15** and a shape of the opening **16***b* of the outer magnetic pole **16** are circles. A diameter of the opening **15***b* of the inner magnetic pole **15** and a diameter of the opening **16***b* of the outer magnetic pole **16** are equal to each other.

A gap (a void) **18** is provided between the tip section **15***a* of the inner magnetic pole **15** and the tip section **16***a* of the outer magnetic pole **16**. The gap **18** has a ring shape that surrounds the optical axis L and, more specifically, a cylindrical surface shape with the optical axis L as a central axis. In the objective lens **100**, since the tip section **16***a* of the outer magnetic pole **16** cantilevers toward the optical axis L, the gap **18** is not facing the direction of the specimen mounting surface **2**. In the illustrated example, the gap **18** faces a direction perpendicular to the optical axis L.

The second magnetic field lens **20** has a second excitation coil **22** and a second yoke **24**. The second excitation coil **22** is connected to a power supply (not illustrated). The second yoke **24** is provided so as to surround the second excitation coil **22**. The second yoke **24** has an inner magnetic pole **25** (an example of the second inner magnetic pole) and an outer magnetic pole **26** (an example of the second outer magnetic pole).

The inner magnetic pole **25** and the outer magnetic pole **26** have a ring shape. The inner magnetic pole **25** is arranged on a side of the optical axis L, and the outer magnetic pole **26** is arranged on an outer side of the inner magnetic pole **25**. The inner magnetic pole **25** extends toward the specimen mounting surface **2** from a portion that surrounds the second excitation coil **22**. In a similar manner, the outer magnetic pole **26** extends toward the specimen mounting surface **2** from a portion that surrounds the second excitation coil **22**.

A distance D4 between a tip section **26***a* of the outer magnetic pole **26** and the specimen mounting surface **2** is shorter than a distance D3 between a tip section **25***a* of the inner magnetic pole **25** and the specimen mounting surface **2**. In other words, in the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** is posi-

tioned between the tip section **25***a* of the inner magnetic pole **25** and the specimen mounting surface **2**.

The tip section **26***a* of the outer magnetic pole **26** cantilevers toward the optical axis L. In other words, the tip section **26***a* of the outer magnetic pole **26** is positioned on a side of the optical axis L as compared to other portions of the outer magnetic pole **26**.

When viewed from the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** overlaps with the specimen movable region **6**. In addition, when viewed from the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** overlaps with the tip section **25***a* of the inner magnetic pole **25**. A distance between the tip section **25***a* of the inner magnetic pole **25** and the optical axis L is equal to a distance between the tip section **26***a* of the outer magnetic pole **26** and the optical axis L.

A center of an opening **25***b* that is defined by the tip section **25***a* of the inner magnetic pole **25** is positioned above the optical axis L. In a similar manner, a center of an opening **26***b* that is defined by the tip section **26***a* of the outer magnetic pole **26** is positioned above the optical axis L. A shape of the opening **25***b* of the inner magnetic pole **25** and a shape of the opening **26***b* of the outer magnetic pole **26** are circles. A diameter of the opening **25***b* of the inner magnetic pole **25** and a diameter of the opening **26***b* of the outer magnetic pole **26** are equal to each other.

A gap (a void) **28** is provided between the tip section **25***a* of the inner magnetic pole **25** and the tip section **26***a* of the outer magnetic pole **26**. The gap **28** has a ring shape that surrounds the optical axis L and, more specifically, a cylindrical surface shape with the optical axis L as a central axis. In the objective lens **100**, since the tip section **16***a* of the outer magnetic pole **16** cantilevers toward the optical axis L, the gap **28** is not facing the direction of the specimen mounting surface **2**. In the illustrated example, the gap **28** faces a direction perpendicular to the optical axis L.

A configuration of the first magnetic field lens **10** and a configuration of the second magnetic field lens **20** are, for example, the same. In addition, the first magnetic field lens **10** and the second magnetic field lens **20** are symmetrically arranged with respect to the virtual plane **4** that includes the specimen mounting surface **2**.

The magnetic field applying unit **30** has a first magnetic field applying coil **32***a*, a second magnetic field applying coil **32***b*, and a magnetic field applying coil yoke **34**.

The first magnetic field applying coil **32***a* is arranged on an outer side of the first excitation coil **12**. For example, the first magnetic field applying coil **32***a* and the first excitation coil **12** are concentrically arranged. The second magnetic field applying coil **32***b* is arranged on an outer side of the second excitation coil **22**. For example, the second magnetic field applying coil **32***b* and the second excitation coil **22** are concentrically arranged.

The magnetic field applying coil yoke **34** is provided so as to surround the first magnetic field applying coil **32***a* and the second magnetic field applying coil **32***b*. The magnetic field applying coil yoke **34** has a columnar shape including an upper surface and a lower surface, and the upper surface and the lower surface are respectively provided with a circular opening that is centered on the optical axis L. The second magnetic field lens **20** is placed on an inner bottom surface of the magnetic field applying coil yoke **34**. In addition, the first magnetic field lens **10** is fixed to an inner upper surface of the magnetic field applying coil yoke **34**.

The position adjusting unit **40** is for adjusting a position of the second magnetic field lens **20** that is placed on the magnetic field applying coil yoke **34**. For example, the position adjusting unit **40** is a position adjusting screw for pushing the second magnetic field lens **20** in a direction (a horizontal direction) that is perpendicular to the optical axis L. Although not illustrated, the screw is provided in plurality and the screws are capable of pushing the second magnetic field lens **20** from mutually different directions. Using the position adjusting unit **40**, the position of the second magnetic field lens **20** with respect to the first magnetic field lens **10** can be adjusted. Accordingly, the first magnetic field lens **10** and the second magnetic field lens **20** can be readily symmetrically arranged with respect to the virtual plane **4**. In addition, by using the position adjusting unit **40**, the second magnetic field lens **20** can be positioned in a state where an electron beam is being irradiated.

The fixing unit **50** is for fixing the second magnetic field lens **20** of which the position has been adjusted to the magnetic field applying coil yoke **34**. The fixing unit **50** is, for example, a bolt, and by screwing the bolt into a female screw provided in the magnetic field applying coil yoke **34**, the second magnetic field lens **20** can be fixed to the magnetic field applying coil yoke **34**.

While the first magnetic field lens **10** is fixed and the position of the second magnetic field lens **20** is adjustable in the illustrated example, alternatively, the position of the first magnetic field lens **10** may be adjustable and the second magnetic field lens **20** may be fixed. In this case, the fixing unit **50** may fix the first magnetic field lens **10** to the magnetic field applying coil yoke **34**. In addition, positions of both the first magnetic field lens **10** and the second magnetic field lens **20** may be made adjustable. In this case, the fixing unit **50** may fix both the first magnetic field lens **10** and the second magnetic field lens **20** to the magnetic field applying coil yoke **34**.

The anti-magnetic tube **60** is arranged between the first magnetic field lens **10** and the second magnetic field lens **20**. The anti-magnetic tube **60** is provided so as to surround a path for loading the specimen S into the objective lens **100** from outside. It should be noted that, in the objective lens **100**, the path for loading the specimen S and a path for extracting the specimen S from inside the objective lens **100** are the same.

The anti-magnetic tube **60** is arranged between the first magnetic field lens **10** and the specimen stage **106** and between the second magnetic field lens **20** and the specimen stage **106**. The anti-magnetic tube **60** is a cylindrical member and has a portion of which a diameter becomes smaller the closer the portion is to the specimen mounting surface **2**. The anti-magnetic tube **60** is constructed of a material with high magnetic permeability. The material of the anti-magnetic tube **60** is, for example, Permalloy.

Since the anti-magnetic tube **60** is provided on the path for loading the specimen S, for example, when the specimen S is sensitive to a magnetic field such as a magnetic specimen, loading of the specimen S and extraction of the specimen S in a state where the objective lens **100** is excited does not have a large impact on a magnetic property of the specimen S.

1.3. Operations of Objective Lens

(1) Operations of First Magnetic Field Lens and Second Magnetic Field Lens

FIG. **4** is a diagram for illustrating magnetic fields generated by the first magnetic field lens **10** and the second magnetic field lens **20**. It should be noted that an X axis, a Y axis, and a Z axis are illustrated in FIG. **4** as three mutually perpendicular axes. The Z axis is an axis along the optical axis L (an axis that is parallel to the optical axis L), and the

X axis and the Y axis are axes that are perpendicular to the optical axis L. In the illustrated example, a Z direction is a vertical direction and the X direction and the Y direction are horizontal directions.

FIG. **5** is a diagram illustrating a distribution of vertical magnetic fields that are generated by the first magnetic field lens **10** and the second magnetic field lens **20**. An abscissa of a graph illustrated in FIG. **5** represents a position on the optical axis L and an ordinate represents a magnitude of a vertical magnetic field (a component in a direction along the optical axis L of the magnetic field, a Z component of the magnetic field).

When an excitation current is supplied to the first excitation coil **12** of the first magnetic field lens **10** from a power supply, the first magnetic field lens **10** generates a first magnetic field B**1** to the front (on a side of the illumination lens, on a side of a −Z direction) of the specimen S. Specifically, when an excitation current is supplied to the first excitation coil **12**, the first excitation coil **12** is excited and a magnetic flux (a magnetic path) is created inside the first yoke **14**. The magnetic flux leaks from the gap **18** between the tip section **15***a* of the inner magnetic pole **15** and the tip section **16***a* of the outer magnetic pole **16** and the first magnetic field B**1** which is rotationally symmetric around the optical axis L is generated. Since the tip section **16***a* of the outer magnetic pole **16** of the first magnetic field lens **10** cantilevers toward the optical axis L, the gap **18** is not facing the direction of the specimen S (the direction of the specimen mounting surface **2**, the Z direction). Therefore, components (X and Y components) in directions perpendicular to the optical axis L of the first magnetic field B**1** are small not only at the specimen origin position of the specimen S but also over a wide range in the vicinity of the specimen S.

In a similar manner, when an excitation current is supplied to the second excitation coil **22** of the second magnetic field lens **20** from the power supply, the second magnetic field lens **20** generates a second magnetic field B**2** to the rear (on a side of the intermediate lens, on a side of a +Z direction) of the specimen S. Specifically, when an excitation current is supplied to the second excitation coil **22**, a magnetic flux (a magnetic path) is created inside the second yoke **24**. The magnetic flux leaks from the gap **28** between the tip section **25***a* of the inner magnetic pole **25** and the tip section **26***a* of the outer magnetic pole **26** and the second magnetic field B**2** which is rotationally symmetric around the optical axis L is generated. Since the tip section **26***a* of the outer magnetic pole **26** of the second magnetic field lens **20** cantilevers toward the optical axis L, the gap **28** is not facing the direction of the specimen S (the direction of the specimen mounting surface **2**, the Z direction). Therefore, components (X and Y components) in directions perpendicular to the optical axis L of the second magnetic field B**2** are small not only at the specimen origin position of the specimen S but also over a wide range in the vicinity of the specimen S.

In this manner, since the tip section **16***a* of the outer magnetic pole **16** of the first magnetic field lens **10** cantilevers toward the optical axis L, a component in a direction that is perpendicular to the optical axis L of the first magnetic field B**1** is prevented from reaching the vicinity of the specimen S. In a similar manner, since the tip section **26***a* of the outer magnetic pole **26** of the second magnetic field lens **20** cantilevers toward the optical axis L, a component in a direction that is perpendicular to the optical axis L of the second magnetic field B**2** is prevented from reaching the vicinity of the specimen S.

The direction of the component (a Z component) along the optical axis L of the first magnetic field B**1** generated by the first magnetic field lens **10** and the direction of the component along the optical axis L of the second magnetic field B**2** generated by the second magnetic field lens **20** are opposite to each other. Therefore, the component in a direction along the optical axis L of the first magnetic field B**1** and the component in the direction along the optical axis L of the second magnetic field B**2** can be caused to act so as to cancel each other out. Accordingly, as illustrated in FIG. **5**, a magnetic field of a direction along the optical axis L on the specimen mounting surface **2** can be made extremely small.

(2) Operations of Magnetic Field Applying Unit

FIG. **6** is a diagram for illustrating operations of the magnetic field applying unit **30**. FIG. **7** is a diagram which illustrates operations of the magnetic field applying unit **30** and which is an enlarged view of a region VII in FIG. **6**. Arrows illustrated in FIGS. **6** and **7** represent a path (a magnetic path) of a magnetic flux generated by the magnetic field applying unit **30**.

As illustrated in FIGS. **6** and **7**, in the objective lens **100**, a path (a magnetic path) of a magnetic flux that passes the tip section **26***a* of the outer magnetic pole **26** of the second magnetic field lens **20**, a space between the tip section **26***a* of the outer magnetic pole **26** and the tip section **16***a* of the outer magnetic pole **16**, and the tip section **16***a* of the outer magnetic pole **16** of the first magnetic field lens **10** can be formed by the magnetic field applying unit **30**. The space between the tip section **26***a* of the outer magnetic pole **26** and the tip section **16***a* of the outer magnetic pole **16** includes the specimen mounting surface **2**.

As a result, in the objective lens **100**, a magnetic field B**3** (a magnetic field in the Z direction) in a direction along the optical axis L can be generated in the space between the tip section **26***a* of the outer magnetic pole **26** and the tip section **16***a* of the outer magnetic pole **16**. Therefore, in the objective lens **100**, the magnetic field B**3** in a direction along the optical axis L can be applied to the specimen S when observing the specimen S. Accordingly, for example, when the specimen S is a magnetic material, a process by which a magnetic property is changed by the magnetic field B**3** and the like can be observed.

1.4. Control Method of Transmission Electron Microscope

Next, a method of controlling the transmission electron microscope **1000** will be described. Hereinafter, a case of acquiring a transmission electron microscope image of the specimen S in a state where the magnetic field B**3** is applied to the specimen S by the magnetic field applying unit **30** will be described.

The method of controlling the transmission electron microscope **1000** includes: a step of causing the first magnetic field lens **10** to generate the first magnetic field B**1** and causing the second magnetic field lens **20** to generate the second magnetic field B**2**; a step of generating a magnetic field of a direction along the optical axis L on the specimen mounting surface **2** using the magnetic field applying unit **30**; and a step of correcting a deviation of a focal length of the objective lens **100** due to the magnetic field generated by the magnetic field applying unit **30** by changing excitations of the first excitation coil **12** and the second excitation coil **22**.

(1) Step of Generating First Magnetic Field B**1** and Second Magnetic Field B**2**

First, the first magnetic field lens **10** is caused to generate the first magnetic field B**1** and the second magnetic field lens **20** is caused to generate the second magnetic field B**2**.

Specifically, a current is supplied to the first excitation coil **12** and the second excitation coil **22**. A current amount to be supplied to the first excitation coil **12** and the second excitation coil **22** is determined by optical conditions (for example, a focal length) of the objective lens **100**.

By causing the first magnetic field lens **10** to generate the first magnetic field B**1** and causing the second magnetic field lens **20** to generate the second magnetic field B**2**, the objective lens **100** forms a transmission electron microscope image. As a result, the transmission electron microscope **1000** enters a state where the specimen S can be observed.

(2) Step of Generating Magnetic Field B**3**

Next, using the magnetic field applying unit **30**, the magnetic field B**3** in a direction along the optical axis L is generated on the specimen mounting surface **2**. Specifically, the magnetic field B**3** is generated on the specimen mounting surface **2** by supplying a current to the first magnetic field applying coil **32***a* and the second magnetic field applying coil **32***b*. A current amount to be supplied to the first magnetic field applying coil **32***a* and the second magnetic field applying coil **32***b* is determined by a size of the magnetic field B**3**. In addition, a direction of the current to be supplied to the first magnetic field applying coil **32***a* and the second magnetic field applying coil **32***b* is determined by a direction of the magnetic field B**3**. In the transmission electron microscope **1000**, an arbitrary magnetic field can be applied to the specimen S.

(3) Step of Correcting Deviation of Focal Length of Objective Lens

FIG. **8** is a diagram schematically illustrating how the magnetic field B**3** is being applied to the specimen S by the magnetic field applying unit **30**. In FIG. **8**, the direction of the magnetic field B**3** is a −Z direction.

The magnetic field B**3** generated by the magnetic field applying unit **30** leaks to the first magnetic field lens **10** and the second magnetic field lens **20**. In the example illustrated in FIG. **8**, the magnetic field B**3** is in the −Z direction and the first magnetic field B**1** is in the +Z direction. In other words, the direction of the magnetic field B**3** and the direction of the first magnetic field B**1** are opposite directions. Therefore, the first magnetic field B**1** is weakened by the leakage of the magnetic field B**3**. In addition, the second magnetic field B**2** is in the −Z direction. In other words, the direction of the magnetic field B**3** and the direction of the second magnetic field B**2** are the same direction. Therefore, the second magnetic field B**2** is strengthened by the leakage of the magnetic field B**3**.

A change in a magnetic field acting on an electron beam due to the leakage of the magnetic field B**3** that is generated by the magnetic field applying unit **30** causes the focal length of the objective lens **100** to change. A change in the focal length of the objective lens **100** changes a magnification, a rotation of an image, conditions of aberration correction, and the like. Therefore, a good transmission electron microscope image cannot be obtained.

Thus, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** is corrected by changing excitations of the first excitation coil **12** and the second excitation coil **22**. As a result, with the transmission electron microscope **1000**, a good transmission electron microscope image can be obtained in a state where the magnetic field B**3** is applied to the specimen S.

For example, when the magnetic field B**3** and the first magnetic field B**1** are in the same direction, excitation of the first excitation coil **12** is weakened and excitation of the second excitation coil **22** is strengthened. On the other hand, when the magnetic field B**3** and the second magnetic field B**2** are in the same direction, excitation of the first excitation coil **12** is strengthened and excitation of the second excitation coil **22** is weakened. In the example illustrated in FIG. **8**, since the magnetic field B**3** and the second magnetic field B**2** are in the same direction, excitation of the first excitation coil **12** is strengthened and excitation of the second excitation coil **22** is weakened.

By correcting a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3**, the focal length of the objective lens **100** can be brought close to the focal length prior to generating the magnetic field B**3**.

FIG. **9** is a diagram schematically illustrating how the magnetic field B**3** is being applied to the specimen S by the magnetic field applying unit **30**. In FIG. **9**, the direction of the magnetic field B**3** is a +Z direction.

In the example illustrated in FIG. **9**, the magnetic field B**3** is in the +Z direction and the first magnetic field B**1** is in the −Z direction. In other words, the direction of the magnetic field B**3** and the direction of the first magnetic field B**1** are opposite directions. Therefore, the first magnetic field B**1** is weakened by the leakage of the magnetic field B**3**. In addition, the second magnetic field B**2** is in the +Z direction. In other words, the direction of the magnetic field B**3** and the direction of the second magnetic field B**2** are the same direction. Therefore, the second magnetic field B**2** is strengthened by the leakage of the magnetic field B**3**. Thus, in the example illustrated in FIG. **9**, excitation of the first excitation coil **12** is strengthened and excitation of the second excitation coil **22** is weakened.

The direction of the first magnetic field B**1** and the direction of the second magnetic field B**2** are changed between a case where the magnetic field B**3** is in the +Z direction as illustrated in FIG. **8** and a case where the magnetic field B**3** is in the −Z direction as illustrated in FIG. **9**. Specifically, even when the direction of the magnetic field B**3** is changed, the direction of the magnetic field B**3** and the direction of the second magnetic field B**2** are made the same. Accordingly, even when the leakage of the magnetic field B**3** is large, the focal length of the second magnetic field lens **20** which is an important lens in terms of image formation can be more accurately corrected. A reason therefor will be described below.

In the transmission electron microscope **1000**, the objective lens **100** is mainly used for image formation. In the objective lens **100**, the lens that is important in terms of image formation is the second magnetic field lens **20** which creates the second magnetic field B**2** that acts on an electron beam having been transmitted through the specimen S.

Although not illustrated, a case where the direction of the magnetic field B**3** and the direction of the second magnetic field B**2** are opposite directions will be considered. In this case, excitation of the second excitation coil **22** is strengthened. However, since there is a limit to an excitation amount of the second excitation coil **22**, when a leakage exceeding this limit occurs, the focal length of the second magnetic field lens **20** can no longer be corrected.

In contrast, as illustrated in FIGS. **8** and **9**, when the direction of the magnetic field B**3** and the direction of the second magnetic field B**2** are the same direction, excitation of the second excitation coil **22** is weakened. Therefore, even when the leakage of the magnetic field B**3** is large, the focal length of the second magnetic field lens **20** can be corrected.

When the transmission electron microscope **1000** is a scanning transmission electron microscope, the objective lens **100** is mainly used to focus an electron beam and form an electron probe. In the objective lens **100**, the lens that is

important in terms of forming an electron probe is the first magnetic field lens **10** which creates the first magnetic field B**1** that acts on an electron beam incident to the specimen S. Therefore, when the transmission electron microscope **1000** is a scanning transmission electron microscope, the direction of the magnetic field B**3** and the direction of the first magnetic field B**1** are made the same.

In this case, an amount of change of excitation of the first excitation coil **12** and an amount of change of excitation of the second excitation coil **22** are determined by the size and the direction of the magnetic field B**3**. Thus, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** is corrected by adjusting the excitation of the first excitation coil **12** and the excitation of the second excitation coil **22** in a state where the magnetic field B**3** is actually being applied to a standard specimen. Excitation conditions of the first excitation coil **12** and the second excitation coil **22** at this point are recorded. This operation is repeated at different sizes and directions of the magnetic field B**3**. Based on excitation conditions obtained in this manner, a database of the excitation conditions of the first excitation coil **12** and the second excitation coil **22** is created. In the database, excitation conditions of the first excitation coil **12** and the second excitation coil **22** for correcting a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** are registered for each size and each direction of the magnetic field B**3**. By referring to the database, the deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** can be readily corrected.

1.5. Processing

Next, processing performed by the control unit **120** will be described. FIG. **10** is a flow chart illustrating an example of processing performed by the control unit **120** of the transmission electron microscope **1000**.

First, the control unit **120** determines whether input of optical conditions of the objective lens **100** has been performed (S**100**) and stands by until input of optical conditions is performed (No in S**100**).

When the control unit **120** determines that input of optical conditions of the objective lens **100** has been performed (Yes in S**100**), the control unit **120** supplies a current to the first excitation coil **12** based on the input optical conditions and causes the first magnetic field lens **10** to generate the first magnetic field B**1** and, at the same time, supplies a current to the second excitation coil **22** based on the input optical conditions and causes the second magnetic field lens **20** to generate the second magnetic field B**2** (S**102**). Accordingly, a transmission electron microscope image is formed in the transmission electron microscope **1000**.

Next, the control unit **120** determines whether information on the magnetic field B**3** to be applied to the specimen S has been input (S**104**) and stands by until input of optical conditions is performed (No in S**104**). The information on the magnetic field B**3** includes information on the size of the magnetic field B**3** and the direction of the magnetic field B**3**.

When the control unit **120** determines that information on the magnetic field B**3** has been input (Yes in S**104**), the control unit **120** generates the magnetic field B**3** in a direction along the optical axis L on the specimen mounting surface **2** using the magnetic field applying unit **30** (S**106**). For example, the control unit **120** generates the magnetic field B**3** by supplying a current to the first magnetic field applying coil **32***a* and the second magnetic field applying coil **32***b* based on the information on the magnetic field B**3**. Accordingly, the magnetic field B**3** is applied to the specimen S.

Next, by changing excitations of the first excitation coil **12** and the second excitation coil **22**, the control unit **120** corrects a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** generated by the magnetic field applying unit **30** (S**108**). Accordingly, the deviation of the focal length of the objective lens **100** is corrected and a good transmission electron microscope image can be obtained in a state where the magnetic field B**3** is applied to the specimen S.

In the storage unit **122**, excitation conditions of the first excitation coil **12** and the second excitation coil **22** for correcting a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** generated by the magnetic field applying unit **30** are stored for each size and each direction of the magnetic field B**3**. The control unit **120** reads excitation conditions of the first excitation coil **12** and the second excitation coil **22** in accordance with the size and the direction of the magnetic field B**3** from the storage unit **122** and determines the excitation conditions of the first excitation coil **12** and the second excitation coil **22**.

1.6. Features

For example, the method of controlling the transmission electron microscope **1000** has the following features.

The method of controlling the transmission electron microscope **1000** includes: a step of causing the first magnetic field lens **10** to generate the first magnetic field B**1** and causing the second magnetic field lens **20** to generate the second magnetic field B**2**; a step of generating the magnetic field B**3** in a direction along the optical axis L on the specimen mounting surface **2** using the magnetic field applying unit **30**; and a step of correcting a deviation of a focal length of the objective lens **100** due to the magnetic field generated by the magnetic field applying unit **30** by changing excitations of the first excitation coil **12** and the second excitation coil **22**. Consequently, according to the method of controlling the transmission electron microscope **1000**, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** can be corrected. Therefore, a good transmission electron microscope image can be obtained in a state where an arbitrary magnetic field is applied to the specimen S.

For example, when the deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** is extremely large, a problem occurs in that an image cannot be formed within a movable range of the specimen S in the Z direction. According to the method of controlling the transmission electron microscope **1000**, such a problem does not occur.

With the method of controlling the transmission electron microscope **1000**, in the step of correcting a deviation of optical conditions of the objective lens **100**, when the magnetic field B**3** generated by the magnetic field applying unit **30** and the first magnetic field B**1** are in the same direction, excitation of the first excitation coil **12** is weakened and excitation of the second excitation coil **22** is strengthened, but when the magnetic field B**3** generated by the magnetic field applying unit **30** and the second magnetic field B**2** are in the same direction, excitation of the first excitation coil **12** is strengthened and excitation of the second excitation coil **22** is weakened. Accordingly, the deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** can be corrected.

For example, the transmission electron microscope **1000** has the following features.

The transmission electron microscope **1000** performs: processing of causing the first magnetic field lens **10** to generate the first magnetic field B**1** and causing the second

magnetic field lens **20** to generate the second magnetic field B**2**; processing of generating the magnetic field B**3** in a direction along the optical axis L on the specimen mounting surface **2** using the magnetic field applying unit **30**; and processing of correcting a deviation of a focal length of the objective lens **100** caused by the magnetic field B**3** generated by the magnetic field applying unit **30** by changing excitations of the first excitation coil **12** and the second excitation coil **22**. Consequently, with the transmission electron microscope **1000**, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** generated by the magnetic field applying unit **30** can be corrected. Therefore, with the transmission electron microscope **1000**, a good transmission electron microscope image can be obtained in a state where an arbitrary magnetic field is applied to the specimen S.

The transmission electron microscope **1000** includes the storage unit **122** in which excitation conditions of the first excitation coil **12** and the second excitation coil **22** for correcting a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** generated by the magnetic field applying unit **30** are stored for each size and each direction of the magnetic field B**3** generated by the magnetic field applying unit **30**. Consequently, with the transmission electron microscope **1000**, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** can be readily corrected.

1.7. Modification of Objective Lens

FIG. **11** is a sectional view schematically illustrating an objective lens **200** according to a modification.

In the objective lens **100** described above, when viewed from the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** and the tip section **15***a* of the inner magnetic pole **15** of the first magnetic field lens **10** overlap with each other as illustrated in FIG. **3**. In a similar manner, when viewed from the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** and the tip section **25***a* of the inner magnetic pole **25** of the second magnetic field lens **20** overlap with each other.

By comparison, in the objective lens **200**, when viewed from the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** and the tip section **15***a* of the inner magnetic pole **15** of the first magnetic field lens **10** do not overlap with each other as illustrated in FIG. **11**. However, in the objective lens **200**, when viewed from the direction along the optical axis L, the tip section **16***a* of the outer magnetic pole **16** of the first magnetic field lens **10** overlaps with the specimen movable region **6**.

In a similar manner, in the objective lens **200**, when viewed from the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** and the tip section **25***a* of the inner magnetic pole **25** of the second magnetic field lens **20** do not overlap with each other. However, in the objective lens **200**, when viewed from the direction along the optical axis L, the tip section **26***a* of the outer magnetic pole **26** of the second magnetic field lens **20** overlaps with the specimen movable region **6**.

In the objective lens **200**, the magnetic fields generated by the first magnetic field lens **10** and the second magnetic field lens **20** can be prevented from leaking to a vicinity of the specimen S in a similar manner to the objective lens **100**.

It should be noted that, in the objective lens **200**, an effect of preventing the magnetic fields generated by the first magnetic field lens **10** and the second magnetic field lens **20** from leaking to the vicinity of the specimen S is smaller than that of the objective lens **100**. However, with the objective lens **200**, a size in a direction along the optical axis L of a space in which the specimen S is arranged can be widened as compared to the objective lens **100**. Therefore, with the objective lens **200**, the specimen S can be tilted by a greater angle.

2. Second Embodiment

2.1. Configuration of Transmission Electron Microscope

Next, a configuration of a transmission electron microscope according to a second embodiment will be described.

FIG. **12** is a diagram schematically illustrating a transmission electron microscope **2000** according to the second embodiment. FIG. **13** is a diagram schematically illustrating substantial parts of the transmission electron microscope **2000** according to the second embodiment. Hereinafter, in the transmission electron microscope **2000** according to the second embodiment, members having similar functions to the components of the transmission electron microscope **1000** according to the first embodiment will be denoted by same reference characters and a detailed description thereof will be omitted.

As illustrated in FIGS. **12** and **13**, the transmission electron microscope **2000** includes a first alignment coil **116** and a second alignment coil **118**. In addition, in the transmission electron microscope **2000**, the control unit **120** controls the illumination lens **104**, the objective lens **100**, the first alignment coil **116**, the second alignment coil **118**, the intermediate lens **110**, and the projector lens **112**.

The first alignment coil **116** and the second alignment coil **118** are arranged along the optical axis L so as to sandwich the specimen mounting surface **2** (refer to FIG. **3** and the like). In the illustrated example, the first alignment coil **116** is arranged between the illumination lens **104** and the specimen mounting surface **2**. The second alignment coil **118** is arranged between the specimen mounting surface **2** and the intermediate lens **110**. The first alignment coil **116** is constituted by, for example, two coils arranged along the optical axis L. The second alignment coil **118** is constituted by, for example, two coils arranged along the optical axis L.

2.2. Control Method of Transmission Electron Microscope

Next, a method of controlling the transmission electron microscope **2000** will be described. The following description will focus on points that differ from the method of controlling the transmission electron microscope **1000** described above, and description of similar points will be omitted.

In the transmission electron microscope **1000** described above, a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3** is corrected by changing excitations of the first excitation coil **12** and the second excitation coil **22**.

However, there are cases where, even by changing the excitations of the first excitation coil **12** and the second excitation coil **22**, a deviation of the optical conditions of the objective lens **100** caused by the magnetic field B**3** cannot be completely corrected.

(1) Correction of Axial Deviation

There are cases where an axial deviation caused by the magnetic field B**3** cannot be corrected even by changing excitations of the first excitation coil **12** and the second excitation coil **22**. In this case, an axial deviation refers to a phenomenon in which an electron beam does not coincide with the optical axis L and deviates from the optical axis L. When an axial deviation caused by the magnetic field B**3** occurs, a deviation of a field of view or a deviation of an aberration occurs.

Therefore, in the transmission electron microscope **2000**, an axial deviation is corrected using the first alignment coil **116** and the second alignment coil **118**. Specifically, by deflecting an electron beam with the first alignment coil **116** and the second alignment coil **118**, an axial deviation caused by the magnetic field B**3** is corrected.

(2) Correction of Magnification

There are cases where a deviation of magnification cannot be corrected even by changing excitations of the first excitation coil **12** and the second excitation coil **22**. In other words, there are cases where a deviation of magnification occurs between before generating the magnetic field B**3** and after generating the magnetic field B**3**. Therefore, in the transmission electron microscope **2000**, a deviation of magnification caused by the magnetic field B**3** is corrected by changing excitation conditions of the intermediate lens **110** and the projector lens **112**.

(3) Correction of Rotation of Image

There are cases where a rotation of an image cannot be corrected even by changing excitations of the first excitation coil **12** and the second excitation coil **22**. In other words, there are cases where applying the magnetic field B**3** causes an image to rotate. A rotation of an image is, for example, a rotation of the image with a center of the image as a rotational axis. For example, when the image rotates by 180 degrees, top and bottom of the image are inverted.

In the transmission electron microscope **2000**, a rotation of an image caused by the magnetic field B**3** is corrected by changing excitation conditions of the intermediate lens **110** and the projector lens **112**.

(4) Correction of Camera Length

There are cases where a deviation of a camera length cannot be corrected even by changing excitations of the first excitation coil **12** and the second excitation coil **22**. In other words, there are cases where a change of the camera length occurs between before applying the magnetic field B**3** and after applying the magnetic field B**3**.

In the transmission electron microscope **2000**, a deviation of the camera length caused by the magnetic field B**3** is corrected by changing excitation conditions of the intermediate lens **110** and the projector lens **112**.

(5) Correction by Illumination Lens

When a deviation of optical conditions of the objective lens **100** caused by the magnetic field B**3** cannot be completely corrected even by changing excitations of the first excitation coil **12** and the second excitation coil **22**, a deviation of the optical conditions of the objective lens **100** which cannot be corrected by changing excitations of the excitations of the first excitation coil **12** and the second excitation coil **22** may be corrected by changing excitation conditions of the illumination lens **104**.

2.3. Processing

Next, processing performed by the control unit **120** will be described. FIG. **14** is a flow chart illustrating an example of processing performed by the control unit **120** of the transmission electron microscope **2000**. It should be noted that, in FIG. **14**, steps of performing the same processing as those of FIG. **10** are denoted by same reference characters. Hereinafter, descriptions of such steps of performing the same processing as those of FIG. **10** will be omitted.

After correcting a deviation of the focal length of the objective lens **100** caused by the magnetic field B**3**, the control unit **120** corrects an axial deviation using the first alignment coil **116** and the second alignment coil **118** (S**110**).

Next, the control unit **120** corrects a deviation of magnification caused by the magnetic field B**3** by changing excitation conditions of the intermediate lens **110** and the projector lens **112** (S**112**).

Next, the control unit **120** corrects a rotation of an image caused by the magnetic field B**3** by changing excitation conditions of the intermediate lens **110** and the projector lens **112** (S**114**). Accordingly, the deviation of optical conditions caused by the magnetic field B**3** is corrected and a good transmission electron microscope image can be obtained in a state where the magnetic field B**3** is applied to the specimen S.

In this case, the excitation conditions of the first excitation coil **12** and the second excitation coil **22**, the excitation conditions of the first alignment coil **116** and the second alignment coil **118**, and the excitation conditions of the intermediate lens **110** and the projector lens **112** are determined by the size and the direction of the magnetic field B**3**.

For this reason, the storage unit **122** stores, for each size and size of the magnetic field B**3**, the excitation conditions of the first excitation coil **12** and the second excitation coil **22**, the excitation conditions of the first alignment coil **116** and the second alignment coil **118**, and the excitation conditions of the intermediate lens **110** and the projector lens **112** for correcting a deviation of the optical conditions caused by the magnetic field B**3**. The control unit **120** reads the excitation conditions of the first excitation coil **12** and the second excitation coil **22**, the excitation conditions of the first alignment coil **116** and the second alignment coil **118**, and the excitation conditions of the intermediate lens **110** and the projector lens **112** in accordance with the size and the direction of the magnetic field B**3** from the storage unit **122** and determines the excitation conditions.

While a case where processing is performed in the order of step S**110**, step S**112**, and step S**114** has been described above, this order is not particularly limited.

2.4. Features

For example, the method of controlling the transmission electron microscope **2000** has the following features.

The method of controlling the transmission electron microscope **2000** further includes a step of correcting an axial deviation of an electron beam with respect to the optical axis L caused by the magnetic field B**3** by deflecting the electron beam with the first alignment coil **116** and the second alignment coil **118**. Consequently, according to the method of controlling the transmission electron microscope **2000**, an axial deviation caused by the magnetic field B**3** can be corrected.

The method of controlling the transmission electron microscope **2000** further includes a step of correcting a deviation of magnification caused by the magnetic field B**3** by changing excitation conditions of the intermediate lens **110** and the projector lens **112**. Consequently, according to the method of controlling the transmission electron microscope **2000**, a deviation of magnification caused by the magnetic field B**3** can be corrected.

The method of controlling the transmission electron microscope **2000** further includes a step of correcting a rotation of an image caused by the magnetic field B**3** by changing the excitation conditions of the intermediate lens **110** and the projector lens **112**. Consequently, according to the method of controlling the transmission electron microscope **2000**, a rotation of an image caused by the magnetic field B**3** can be corrected.

3. Third Embodiment

3.1. Configuration of Transmission Electron Microscope

Next, a transmission electron microscope according to a third embodiment will be described. FIG. **15** is a diagram illustrating a configuration of a transmission electron microscope **3000** according to the third embodiment. Hereinafter, in the transmission electron microscope **3000** according to the third embodiment, members having similar functions to the components of the transmission electron microscope **1000** according to the first embodiment and the transmission electron microscope **2000** according to the second embodiment will be denoted by same reference characters and a detailed description thereof will be omitted.

As illustrated in FIG. **15**, the transmission electron microscope **3000** includes a scanning coil **105** for scanning a surface of the specimen S with an electron beam and a detector **115** for detecting electrons having been transmitted through the specimen S. In other words, the transmission electron microscope **3000** is a scanning transmission electron microscope.

In the transmission electron microscope **3000**, an electron beam discharged from the electron source **102** is focused by the illumination lens **104** and the objective lens **100** to form an electron probe and illuminate the specimen S. An electron beam to illuminate the specimen S is caused to scan a surface of the specimen S by the scanning coil **105**. An electron beam having been transmitted through the specimen S is guided to the detector **115** by the objective lens **100**, the intermediate lens **110**, and the projector lens **112**, and is detected by the detector **115**. A detection signal of the detector **115** is associated with information on an illumination position on the specimen S. Accordingly, a scanning transmission electron microscope image can be acquired.

A magnification of the scanning transmission electron microscope image is determined by a size of a region having been scanned by an electron beam. In addition, a direction of the scanning transmission electron microscope image is determined by a scanning direction.

The control unit **120** controls the scanning coil **105**.

3.2. Control Method of Transmission Electron Microscope

Next, a method of controlling the transmission electron microscope **3000** will be described. The following description will focus on points that differ from the method of controlling the transmission electron microscope **1000** and the method of controlling the transmission electron microscope **2000** described above, and description of similar points will be omitted.

In the transmission electron microscope **2000** described above, a deviation of magnification caused by the magnetic field B**3** is corrected by changing excitation conditions of the intermediate lens **110** and the projector lens **112**.

By comparison, in the transmission electron microscope **3000**, a deviation of magnification caused by the magnetic field B**3** is corrected by changing, using the scanning coil **105**, a size of a region to be scanned by an electron beam.

In addition, in the transmission electron microscope **2000** described above, a rotation of an image caused by the magnetic field B**3** is corrected by changing excitation conditions of the intermediate lens **110** and the projector lens **112**.

By comparison, in the transmission electron microscope **3000**, a rotation of an image caused by the magnetic field B**3** is corrected by changing a scanning direction using the scanning coil **105**.

3.3. Processing

Processing performed by the control unit **120** of the transmission electron microscope **3000** is the same as the processing performed by the control unit **120** of the transmission electron microscope **2000** with the exception of using the scanning coil **105** in the processing of correcting a magnification (S**112**) and the processing of correcting a rotation of an image (S**114**) illustrated in FIG. **14**, and descriptions of the processing will be omitted.

3.4. Features

The method of controlling the transmission electron microscope **3000** further includes a step of correcting a deviation of magnification caused by the magnetic field B**3** by changing, using the scanning coil **105**, a size of a region to be scanned by an electron beam. Consequently, according to the method of controlling the transmission electron microscope **3000**, a deviation of magnification caused by the magnetic field B**3** can be corrected.

The method of controlling the transmission electron microscope **3000** further includes a step of correcting a rotation of an image caused by the magnetic field B**3** by changing, using the scanning coil **105**, a scanning direction of an electron beam. Consequently, according to the method of controlling the transmission electron microscope **3000**, a rotation of an image caused by the magnetic field B**3** can be corrected.

The invention includes configurations that are substantially the same (for example, in function, method, and results, or in objective and effects) as the configurations described in the embodiments. The invention also includes configurations in which non-essential elements described in the embodiments are replaced by other elements. The invention also includes configurations having the same effects as those of the configurations described in the embodiments, or configurations capable of achieving the same objectives as those of the configurations described in the embodiments. The invention further includes configurations obtained by adding known art to the configurations described in the embodiments.

Some embodiments of the invention have been described in detail above, but a person skilled in the art will readily appreciate that various modifications can be made from the embodiments without materially departing from the novel teachings and effects of the invention. Accordingly, all such modifications are assumed to be included in the scope of the invention.

What is claimed is:

1. A method of controlling a transmission electron microscope that comprises an objective lens, the objective lens comprising:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field generator which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole, and

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other,

the method of controlling a transmission electron microscope comprising:

causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

causing the magnetic field generator to generate a magnetic field of a direction along the optical axis on the specimen mounting surface; and

changing excitations of the first excitation coil and the second excitation coil to correct a deviation of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field generator.

2. The method of controlling a transmission electron microscope according to claim **1**, wherein

in correcting a deviation of a focal length of the objective lens,

when the direction of the magnetic field generated by the magnetic field generator is the same as the direction of the first magnetic field, excitation of the first excitation coil is weakened and excitation of the second excitation coil is strengthened, and

when the direction of the magnetic field generated by the magnetic field generator is the same as the direction of the second magnetic field, excitation of the first excitation coil is strengthened and excitation of the second excitation coil is weakened.

3. The method of controlling a transmission electron microscope according to claim **1**, wherein

the transmission electron microscope further comprises a first alignment coil and a second alignment coil arranged along the optical axis so as to sandwich the specimen mounting surface, and

the method of controlling a transmission electron microscope further comprises: correcting an axial deviation of an electron beam with respect to the optical axis by deflecting an electron beam with the first alignment coil and the second alignment coil, the axial deviation being caused by the magnetic field generated by the magnetic field generator.

4. The method of controlling a transmission electron microscope according to claim **1**, wherein

the transmission electron microscope further comprises an intermediate lens and a projector lens,

the objective lens, the intermediate lens, and the projector lens constitute an imaging system of the transmission electron microscope, and

the method of controlling a transmission electron microscope further comprises: correcting a deviation of magnification by changing excitation conditions of the intermediate lens and the projector lens, the deviation of magnification being caused by the magnetic field generated by the magnetic field generator.

5. The method of controlling a transmission electron microscope according to claim **1**, wherein

the transmission electron microscope includes a scanning coil used for scanning a surface of the specimen with an electron beam, and

the method of controlling a transmission electron microscope further comprises correcting a deviation of magnification by changing a size of a region of the specimen to be scanned with an electron beam by using the scanning coil, the deviation of magnification being caused by the magnetic field generated by the magnetic field generator.

6. A transmission electron microscope comprising:

an objective lens; and

a control unit that controls the objective lens,

the objective lens comprising:

a first magnetic field lens and a second magnetic field lens which are arranged along an optical axis so as to sandwich a specimen mounting surface on which a specimen is to be mounted; and

a magnetic field generator which generates a magnetic field of a direction along the optical axis on the specimen mounting surface,

the first magnetic field lens having a first inner magnetic pole, a first outer magnetic pole, and a first excitation coil,

the second magnetic field lens having a second inner magnetic pole, a second outer magnetic pole, and a second excitation coil,

a distance between a tip section of the first outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the first inner magnetic pole and the specimen mounting surface,

a distance between a tip section of the second outer magnetic pole and the specimen mounting surface being shorter than a distance between a tip section of the second inner magnetic pole and the specimen mounting surface,

the first magnetic field lens generating a first magnetic field by exciting the first excitation coil to cause a magnetic flux to leak from a gap between the first inner magnetic pole and the first outer magnetic pole,

the second magnetic field lens generating a second magnetic field by exciting the second excitation coil to cause a magnetic flux to leak from a gap between the second inner magnetic pole and the second outer magnetic pole, and

a direction of a component of the first magnetic field along the optical axis and a direction of a component of the second magnetic field along the optical axis being opposite to each other, and

the control unit performing:

processing of causing the first magnetic field lens to generate the first magnetic field and causing the second magnetic field lens to generate the second magnetic field;

processing of causing the magnetic field generator to generating a magnetic field of a direction along the optical axis on the specimen mounting surface; and

processing of changing excitations of the first excitation coil and the second excitation coil to correct a deviation

of a focal length of the objective lens, the deviation being caused by the magnetic field generated by the magnetic field generator.

7. The transmission electron microscope according to claim **6**, comprising

a storage unit in which excitation conditions of the first excitation coil and the second excitation coil for correcting a deviation of a focal length of the objective lens are stored for each size and each direction of the magnetic field generated by the magnetic field generator, the deviation being caused by a magnetic field generated by the magnetic field generator.

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